STATE OF ALASKA

DEPARTMENT OF FISH AND GAME
OFFICE OF THE COMMISSIONER

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November 6, 2008

Ms. Deanna Lynch
Western Washington Fish and Wildlife Office
U.S. Fish and Wildlife Service
510 Desmond Drive SE, Suite 102
Lacey, Washington 98503

Re: Marbled Murrelet Rangewide Status Review

Dear Ms. Lynch,

Attached is information gathered by the State of Alaska to assist the U.S. Fish and Wildlife Service with the rangewide status review of the Marbled Murrelet. Included are descriptions of existing regulatory and environmental programs in place that conserve Marbled Murrelets in Alaska, as well as summaries of existing information and research efforts.

The attached reports include studies of Marbled Murrelets funded by the Alaska Department of Fish and Game. A report highlighting the pertinent issues regarding the Marbled Murrelet research conducted by former Fish and Game biologist Matt Kirchhoff will be submitted to you in the near future. Matt examined multiple methods for censusing Marbled Murrelets in Southeast Alaska during the years of 2004-2008.

Various methods for collecting and analyzing Marbled Murrelet census data have been used by researchers. We urge your careful consideration of the methodologies used and their limitations, and suggest your rangewide status review incorporate a detailed statistical review of the various analyses.

Thank you for the opportunity to provide you with this information. We are willing to discuss this information in more detail if you wish. If you have any questions, please feel free to contact me.

Sincerely,

Doug Vincent-Lang
Endangered Species Coordinator
Alaska Department of Fish and Game

cc: Doug Larsen—Director, ADF&G/DWC
Mary Rabe—Nongame Coordinator, ADF&G/DWC
Sadie Wright—ESA Team, ADF&G/DWC
Gary Mendivil—Program Coordinator, DEC
Don Perrin—Large Project Coordinator, DNR
Liliana Naves—Research Analyst, ADF&G/Subsistence
Brad Meyen—Department of Law

MARBLED MURRELET INFORMATION:

Provided by the State of Alaska to the U.S. Fish and Wildlife Service to aid in the preparation of the status review for this species.

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STATE REGULATIONS/MANAGEMENT

Department of Environmental Conservation—

Water Quality Management

The Water Division regulates water quality for the State of Alaska through water quality and wastewater standards found in the Alaska Administrative Code at 18 AAC 70, 18 AAC 72 and 18 AAC 83. These regulations provide specificity for the State of Alaska's implementation of the federal Clean Water Act. The state's water quality standards and wastewater regulations are based on the general prohibition principle, such that no person may cause or contribute to a violation of the water quality standards in state waters and discharges to state waters must be authorized by a permit. These water quality standards apply to both marine and fresh waters and protect water quality for a wide variety of uses, including growth and propagation of aquatic life, which includes marine mammals and their prey.

For waters that are of naturally high quality, the water quality standards include an antidegradation provision that prohibits any degradation of water quality unless certain conditions are met and even then all uses still have to be protected. Alaska's water quality standards also apply to waters of the outer continental shelf adjacent to Alaska by virtue of the Alaska Coastal Management Program. The Division's Wastewater Discharge Authorization Program regulates stormwater pollution of water bodies through review and approval of construction plans and stormwater pollution prevention plans from industrial sites.

Oil and gas wastewater discharges

Oil and gas wastewater discharges are mainly permitted through the EPA's NPDES General Permit Cook Inlet Oil and Gas Exploration, Development and Production Facilities. This permit covers discharges on the both the Outer Continental Shelf and state waters in the vicinity of Cook Inlet, Alaska. ADEC issued State Certification of the EPA's NPDES Cook Inlet General Permit in 2007.

Water Quality Monitoring and Assessment

The Clean Water Act mandates that each state develop a program to monitor and report on the quality of it surface and groundwaters and prepare a report describing the status of its water quality. Section 303(d) requires that states list any waterbodies that do not meet water quality standards. Because of Alaska's size, sparse population, and its remote character, the vast majority of Alaska's water resources are in pristine condition. More than 99.9% of Alaska's waters are considered unimpaired. In specific localized parts of Alaska, surface water quality has been impaired. Historically, these waters are predominantly impaired from sediment, turbidity, and fecal coliform bacteria contamination from urban and stormwater runoff.

Petroleum products, such as oil spills or fuel leaks are also a source of impairment. Detailed information on specific water considered impaired can be found in *Alaska's Final 2008 Integrated Water Quality Monitoring and Assessment Report, April 1,2008*, which is available on the Water Quality Standards, Assessment and Restoration

Program's web site. Further data on the condition of water quality, sediments and biology of Alaska's coastal waters is also available from the Alaska Monitoring and Assessment Program, which has done statistically-based regional surveys of the Aleutian Islands, Southcentral Alaska and Southeast Alaska coastal waters.

Oil Spill Prevention and Response

The DEC Division of Spill Prevention and Response (SPAR) is responsible for protecting Alaska's land, waters and air from oil and hazardous substances spills. SPAR regulates spill prevention through review and approval of spill prevention plans for oil terminals, pipelines, tank vessels, barges, refineries, oil exploration facilities and oil production facilities. SPAR ensures response preparedness through the review and approval of oil discharge contingency plans, inspections, oil spill response exercises, oil spill response drills. Oil Spill contingency plans are required under Alaska Statute AS 46.04.030 and Alaska Administrative Code regulations at 18 AAC 75. Oil Spill Proof of Financial Responsibility is required under Alaska Statute AS 46.04.030. The State of Alaska requires oil spill contingency plans for the following facilities:

- Offshore oil and gas exploration facilities
- Onshore oil and gas exploration facilities
- Crude oil transmission pipelines
- Oil flow lines and gathering lines
- Noncrude oil terminals (over 10,000 bbls)

The DEC Spill Prevention and Response (SPAR) Division's mission is to prevent, respond and ensure the cleanup of unauthorized discharges of oil and hazardous substances. The Industry Preparedness Program (IPP) requires regulated facilities and vessels to develop state-approved oil spill response and contingency plans, to establish a facility-wide spill prevention program and to ensure that personnel, equipment and financial resources are available to respond to spills. In the event of a spill, the Prevention and Emergency Response Program (PERP) serves as the State's emergency responders to oil and hazardous substance spills and ensures that cleanup measures are implemented as soon as possible.

Detailed information on historical oil spills is available in the department's latest report, *DEC 10-Year Statewide Summary: Oil and Hazardous Substances Spill Data*, and the *Summary of Oil and Hazardous Substances Spills by Subarea,* both of which are available on the program's web site. This report provided the following conclusions and highlights relating to the marbled murrelet's marine habitat:

- Oil (both crude and noncrude oil products) constitute the vast majority (82%) of the reported spills
- Spills from unregulated vessels were most common for the coastal areas of Southeast Alaska, Prince William Sound, Kodiak, Cook Inlet and the Aleutians.
- Seasonal trends for marine spills occur in the coastal areas of the state during the commercial fishing season, typically April through September.

- Cook Inlet experienced the greatest number of spills. This can be attributed to the higher population and industrial density, plus the major highways, railway and other transportation infrastructure in the area.

Significant Spill Events by Subarea

Aleutians – On December 26, 1988, the Tanker Barge 283 released 2,041,662 gallons of diesel fuel near the Shumagin Islands. On November 26,1997 the M/V Kuroshima grounded near Unalaska Island resulting in a spill of 38,976 gallons of bunker fuel. On December 8, 2004, the Selendang Ayu also went aground near Unalaska Island, releasing 335,732 gallons of diesel fuel.

Prince William Sound – The Exxon Valdez went aground on Bligh Reef on March 24, 1989, releasing 11 million gallons of crude oil, with significant marbled murrelet mortality in coastal and offshore waters following the spill. On August 4, 2001, the F/V Windy Bay struck a reef and sank, releasing 35,000 gallons of diesel fuel.

Additional Information

Alaska's Final 2008 Integrated Water Quality Monitoring and Assessment Report, April 1, 2008 available at
http://www.dec.state.ak.us/water/wqsar/waterbody/2008FinalIntegratedReport3-1908.pdf

DEC Wastewater Permits Database, available at
http://www.dec.state.ak.us/ias/permitsearch/default.aspx

DEC (2007) *DEC 10-Year Statewide Summary: Oil and Hazardous Substances Spill Data* (July 1, 1995 – June 30, 2007) available at
http://www.dec.state.ak.us/spar/perp/subreports.htm

DEC (2007) *Summary of Oil and Hazardous Substance Spills by Subarea (July 1, 1995 – June 30, 2005)*
http://www.dec.state.ak.us/spar/perp/docs/10year_rpt/10Yr_Subareas_FINAL.pdf

Department of Fish and Game

Division of Subsistence—

The ADFG Division of Subsistence has not conducted a dedicated survey to assess customary and traditional uses of marbled or Kittlitz's murrelets and comprehensive household surveys have not specifically inquired about uses of these species. Household surveys conducted in the Aleutians Islands have inquired about ancient murrelets. An estimated harvest of 28 ancient murrelets and 70 ancient murrelet eggs in Unalaska (1994) can be found in the Community Subsistence Information System CSIS (http://www.subsistence.adfg.state.ak.us/CSIS/). An estimated harvest of 14 ancient murrelet eggs in Akutan is reported in Fall et al. (1998) and can be found also in the CSIS. Mention of historic use of ancient murrelets in Atka is reported in Veltre & Veltre (1983, page 139). Uses of marbled or Kittlitz's murrelet in their area of occurrence

cannot be ruled out. However, given the dispersed nesting habits and small size of adults, harvest of eggs (Hunn et al. 2003) and adults may be rather occasional. Besides, people may not know the bird to which eggs gathered from solitary nests belong, which makes harvest assessment difficult.

The Division of Subsistence has not conducted research focusing on traditional ecological knowledge about murrelets and, although information about this subject has not been mentioned in other studies, one should not conclude that traditional ecological knowledge does not exist. In this context, it is of interest to trace references to murrelets in languages spoken in the main distribution area of these species. The Iñupiat Eskimo dictionary (North Slope and Seward Peninsula) did not include a word for murrelets (Webster & Zibell 1970). The Aleut dictionary (Aleutians Islands) presented two nouns from different dialects specifically referring to ancient murrelet, although no reference was made to other murrelet species (Bergsland 1994). The Tlingit dictionary (Southeast Alaska) identified only one word for "auklets or murrelets (diving birds)" (Davis & Leer 1976). However, Hunn et al. (2003) have identified a single Tlingit name for both marbled and Kittlitz' murrelets. What is evident is that native peoples of Southeast Alaska are familiar with these species. Alutiiq (Alaska Peninsula, Kodiak, Kenai Peninsula, Prince William Sound) reference to murrelets could not be found in Leer (1978), Leer et al. (1978), or Leer et al. (1996). This pattern may reflect an incomplete coverage of the languages in the referred dictionaries or suggest that marbled or Kittlitz's murrelets have not been used as primary subsistence or cultural resources.

The Division of Subsistence is not aware of subsistence activities in breeding and feeding grounds that could directly or indirectly interfere with murrelets, although dedicated studies have not been conducted. In Southeast Alaska, while commercial gillnets are operated in open marine waters, subsistence gillnets are set at the mouth of rivers and the nets are closely monitored by the fishers. Setnets in the Chilkat River and rivers in the Yakutat area are set in fresh water or close to shore in marine waters (Turek M, personal comm., ADFG Division of Subsistence, Juneau).

Literature Cited:

Bergsland, K. 1994. Aleut Dictionary. Alaska Native Language Center, University of Alaska Fairbanks.

Davis, H. and Leer, J. 1976. English-Tlingit Dictionary (nouns). Sheldon Jackson College.

Fall, J.A., Paige, A., Vanek, V., and Brown, L. 1998. Subsistence harvests and uses of birds and eggs in four communities of the Aleutian Islands area: Akutan, False Pass, Nelson Lagoon, and Nikolski. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 243.

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NPS D-113. PACIFIC Northwest Cooperative Ecosystem Studies Unit. College of Forest Resources, Seattle.

Leer, J. 1978. A Conversational Dictionary of Kodiak Alutiiq. Alaska Native Language Center. University of Alaska Fairbanks.

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Leer, J., Christiansen, M., Lind, D., Phillips, T., Phillips, R., and Sam, M. 1996. A Short Dictionary of Alaska Peninsula Sugtestun and Alaska Peninsula Alutiiq Workbook. Alaska Native Language Center. University of Alaska Fairbanks.

Veltre, D.W. and Veltre, M.J. 1983. Resource utilization in Atka, Aleutian Islands, Alaska. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 88.

Webster, D.H. and Zibell, W. 1970. Iñupiat Eskimo Dictionary. Summer Institute of Linguistics, Inc., Fairbanks, Alaska.

Department of Natural Resources—

The USGS 2006 "Status Review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia" document summarizes the State of Alaska efforts for conservation of Marbled Murrelets in that management of state lands within the species range provides indirect benefits to Marbled Murrelets. The document states that habitat loss from timber harvest is a major threat to the listed species. In Alaska, where the species is not listed under the ESA, DNR Area Plans provide indirect benefits to the species through management guidelines for forestry and timber harvest. In addition, Area Plans provide land use management guidelines for species that are listed under the ESA. DNR Area Plans are the product of work by State and Federal agencies, other land owners in the area, local governments, special interest groups, and the public. Area Plans within the Marbeled Murrelett's range include:

- Central/Southern Southeast Area Plan
- Prince of Wales Island Area Plan
- Northern Southeast Area Plan
- Yakataga Area Plan
- Prince William Sound Area Plan
- Kodiak Area Plan

These plans can be accessed online at:
http://www.dnr.state.ak.us/mlw/planning/areaplans/

Forestry Management Guidelines

The timing, location, harvest amounts and methods of timber harvests are controlled by state statutes and regulations. The Alaska Land Act (AS 38.05.110-123) and Regulations (11 AAC 71) provide policy and guidance for management of state forest resources. The Forest Resources and Practices Act (AS 41.17) and Regulations (11 AAC 95) provide additional policy and guidance for managing forest related activities.

Area plans adopted under AS 38.04.065 determine whether forest harvest is an appropriate use of state lands. Area plans designate the main uses for state lands, set guidelines to ensure that multiple uses occur compatibly, and classify the land according to its main uses. Land must be classified before it and any interests in the land can be sold (11 AAC 55.040(i)).

Proposed timber sales throughout the state must be included in two consecutive annual five-year Schedule of Timber Sales published by the DNR Division of Forestry (DOF), with certain exceptions. These annual sale schedules identify the location, timing, and volumes of proposed timber harvests on state forestland managed by DNR. Small sales of 10-160 acres are, as a matter of DNR policy, also listed in the five-year sale schedule at least once.

Site-specific guidelines for forest management activities are addressed through a Forest Land Use Plan (FLUP) prior to offering timber for harvest (AS 38.05.112). A Forest Land Use Plan is required for all sales greater than 10 acres. All timber sales must be in the overall best interest of the state. When a written Best Interest Finding is required under AS 38.05.035, it is made part of the FLUP.

Timber Harvest Guidelines

All timber harvest activities must be compatible with the general management guidelines of this section and with the management intent statements and land use designations identified in specific management units of the area plans.

Timber Harvest Stipulations. All timber harvest operations will be conducted in accordance with the stipulations in the Forest Land Use Plan, the Alaska Forest Resources and Practices Act (AS 41.17 & 11 AAC 95), the Alaska Land Act (AS 38.05 & 11 AAC 71), and other pertinent state guidelines and laws.

Forest Land Use Plans (FLUPs). Although an area plan may establish areas of potential timber harvest, it does not make specific timber harvest decisions. Before timber harvest decisions are made for specific locations in planning area, DOF will prepare a Forest Land Use Plan (FLUP), as required under AS 38.05.112, and a Best Interest Finding, required under AS 38.05.035. FLUPs will contain site-specific guidelines for timber harvest. Negotiated timber sales will occur in the future within the planning area that are less than 10 acres in size or less than 500 MBF. These sales do not require a Best Interest

Finding but may require a FLUP if they are greater than 10 acres in size. In either case, they must still adhere to the area plan's standards, guidelines and management intent statements.

Size and Shape of Timber Harvest Units. In determining the size, shape, and spacing of timber harvest units, DOF will take into consideration: reforestation; water body types; effects of soil erosion and mass wasting on water quality and fish habitat; terrain; marketing conditions and other economic constraints; harvest equipment capabilities; efficiency; wind firmness of areas that are not cut. DOF will also make allowances for important fish and wildlife habitat and scenic quality. Harvest units may not exceed 160 acres in size unless approved in an FLUP after consultation with DEC and ADF&G, and public review. The 160-acre limit applies to all harvesting systems except single tree selection. In some subunits, management intent indicates a smaller acreage.

Leave Area Design Criteria. After consultation with ADF&G as part of the FLUP planning process, leave areas that are identified in the approved FLUP, which may include areas of Old Growth Forest, shall be maintained to make allowances for important fish and/or wildlife habitat. The cumulative benefits of the forest wide protections provided by the Chugach and Tongass Land and Resource Management Plans as well as the opportunities for coordinated federal-state land management at the site and regional levels, should be considered in making determinations of the need for and the subsequent design of leave areas. Leave areas provide interconnected habitat for travel, feeding, resting, and escape or avoidance of predators. Areas where evidence of their use by wildlife is found to occur, natural travel corridors such as ridge points, the forested edge of wetlands, the coastal fringe, portions of Old Growth Forest, and riparian corridors should be considered for inclusion within designated leave areas. To achieve this intent, special management areas extending out 300 feet from each bank are designated along anadromous and high value resident fish streams to facilitate wildlife movement, and provide important riparian habitat for fish and wildlife. Special management areas shall be greater where larger widths are specified in the management intent statement for upland tracts. Buffers not less than 330 feet will be left around each bald eagle nesting tree unless, upon consultation with USFWS, a site specific activity may be conducted within 330 feet of the nesting tree. Wind firmness of residual trees will be taken into consideration when designing leave areas between designated cutting units. Bridge timbers may be taken from leave areas if there is no feasible or prudent alternative.

Harvest Unit Layout. A mosaic of forest age classes will be created by cutting units and leave areas where feasible and prudent. DNR will lay out units following DOF's Engineering Guide for Southeast Region.

Timing of Harvest Activity. Among those management units with areas designated Settlement or General Use and identified as suitable for timber harvest, DOF will rotate the location of harvest activities between management units over time. Rotating the location of timber harvest will reduce the level of impacts to any particular management unit at any one time. In general, there should be no more than one timber sale in an area designated Settlement every two years, unless the community or the overall public

interest supports a more active timber harvest program. This policy applies only to timber sales greater than 10 acres.

Steep Slopes. Forest management activities may not be conducted on slopes consistently greater than 67 percent, on an unstable slope, or in a slideprone area unless approved in an FLUP. DNR shall consult with ADF&G on decisions involving timber harvest in areas steeper than 67 percent. Harvest operations will be designed to prevent mass wasting and to maintain soil productivity, tree regeneration, and fish habitat.

Recreation and scenic values. In determining the size and shape of cutting units, DOF shall make allowance for scenic quality in or adjacent to areas of substantial importance to the tourism and recreation industry. In these areas, cutting units will reflect local topography and, to the extent practical, blend in with the topography and minimize linear borders. The relative importance of scenic quality will be specified in the management statements and controlled by the management intent guidelines for each management unit.

Settlement Areas. In areas designated Settlement, state commercial timber sales will adhere to the Forest Resources and Practices Act (FRPA) and pertinent state regulations for commercial forestry, and will not be considered a "land use conversion" as described in FRPA. Such timber harvest shall be direct support of current or future state subdivision development. However, the salvage of damage trees, including beach salvage, is authorized and may occur separately from subdivision development.

Maintenance of Areas adjacent to the Coast. Areas adjacent to the coast shall be maintained in order to achieve the objectives of fisheries and/or wildlife habitat protection; public access; dispersed recreation; scenic viewshed protection; and, within portions of this area, the selective harvest of timber. The width, configuration, and specific management objectives of these areas are identified for affected upland tracts in the management intent statements of the Resource Allocation Tables in the area plan. These areas are to be provided in existing Old Growth Forest areas. The exact configuration of coastal maintenance areas (forestry) are to be determined by ADF&G and DNR during the FLUP planning process. If authorized in the management intent for a specific tract, selective timber harvest may occur beyond the first 500 feet from mean high water, or as otherwise provided in these descriptions. Within a limited number of tracts, either selective harvest or conventional harvest methods may be used within the 500-1,000 foot area, the type depending on the results of the FLUP planning process. It is recognized that divergence from the inland boundary applying to specific tracts may be necessary to provide flexibility for uses and activities permitted by the state, including timber harvest, but shall only be authorized if the overall objectives of the coastal maintenance area are maintained. DNR shall consult with ADF&G in making decisions of this type.

Sustained Yield of Forest Resources Forestland will be managed to guarantee perpetual supplies of renewable resources to serve the needs of all Alaskans for the many products, benefits, and services obtained from them. Annual allowable timber harvest for the

planning area shall be based on the acreage with designations identified as suitable for timber harvest in the Central/Southern Southeast Area Plan, the Prince of Wales Island Area Plan, and the Southwest Prince of Wales Island Area Plan within the Division of Forestry's Ketchikan area, taking into consideration the standards and guidelines of this plan and relevant statutes and regulations. The acreage may change over time as lands are converted to other uses. The number of acres of land suitable for timber harvest will be reviewed and revised periodically, and a new annual allowable harvest calculated. The annual allowable harvest will be calculated using the area control method. The amount of timber harvested annually from the planning area will vary and may be more or less than the annually allowable harvest figure for the area covered by this area plan. However, at no time shall the acreage harvested on a decadal basis exceed the annual allowable harvest for that period within the planning period.

Protection of Fish and Wildlife Habitat. Land designated Forestry, or land where timber harvest is an appropriate use, will be managed for multiple use of all resources and to ensure the sustained yield of renewable resources. Prior to harvest, DNR shall consult with and give due deference to ADF&G on the effects of the proposed harvest on fish and wildlife habitat, and make allowance for important fish and wildlife habitat, as provided under AS 41.16.060 and 41.17.098(d). The relative importance of wildlife habitat will be specified in the management intent statements and controlled by the management guidelines for each management unit. Important fish habitat is defined as a water body supporting anadromous or high quality resident fish, as defined in AS 41.17.118(a)(2)(A) and consistent with the meaning of AS 41.17.060. Timber harvests of less than 10 acres in size are considered consistent with this guideline without consultation unless activities are proposed for which ADF&G has due deference. Riparian areas shall be managed in accordance with AS 41.17.118 and 11 AAC 95.185. No harvest activities will be undertaken within 100 feet of an anadromous or high value resident fish stream except as provided by 11 AAC 95.275 & .355. Within 100-300 feet from the stream, harvest may occur but must be consistent with the maintenance of important fish and wildlife habitat required under AS 41.17.118(a), with due deference to ADF&G.

Threatened and Endangered Species. All land use activities will be conducted consistent with state and federal Endangered Species Acts to avoid jeopardizing the continued existence of threatened or endangered species of animals or plants; or to provide for their continued use of an area and to avoid modification or destruction of their habitat. Specific mitigation recommendations should be identified through interagency consultation for any land use activity that potentially affects threatened or endangered species.

ADF&G FUNDED PROJECTS

Completed Research—

K.J. Kuletz, E.A. Labunski, and S.G. Speckman. 2008. Abundance, distribution, and decadal trends of Kittlitz's and marbled murrelets and other marine species in Kachemak Bay, Alaska. Final Report (Project No. 14) by U.S. Fish and Wildlife Service for Alaska Department of Fish and Game, State Nongame Wildlife Grant, Anchorage, Alaska.
See Appendix A.

C. Nations, L. McDonald, and J. Parrish. 2008. Power to detect trends in *Brachyramphus* Murrelet populations in Southeast Alaska. Final Report for Alaska Department of Fish and Game, State Nongame Wildlife Grant, Anchorage, Alaska.
See Appendix B.

Newman, S.H., S.K. Nelson, D.L. Whitworth, and H.R. Carter. 2006. Marbled Murrelet (*Brachyramphus marmoratus*) activity patterns and health in Port Snettisham, Southeast Alaska, 2005. Unpublished report prepared for the Alaska Department of Fish and Game by Wildlife Trust, New York, NY. 70pp.
See Appendix C.

Newman, S. H., V.M. Padula, S.K. Nelson, and T.B. Haynes. 2008. Health Assessment of Marbled Murrelets in Port Snettisham, SE Alaska. Unpublished report prepared for the Alaska Department of Fish and Game by Wildlife Trust, New York, NY. 45pp.
See Appendix D.

Haynes, T.B., S.K. Nelson, F. Poulsen, and V.M. Padula. 2008. At-sea habitat use and patterns in spatial distribution of Marbled Murrelets in Port Snettisham, SE Alaska. Unpublished report prepared for the Alaska Department of Fish and Game by Wildlife Trust, New York, NY and Oregon State University, Corvallis, OR. 55 pp.
See Appendix E.

Future Research—

Kirchhoff, M. Former Alaska Department of Fish and Game biologist, Matt Kirchhoff, studied Marbled Murrelets in Southeast Alaska from 2004-2008. Prior to the December 1, 2008 deadline, Matt will submit to the USFWS a report outlining his work and focusing on issues pertinent to this rangewide status review. In addition, he will complete a detailed final report that will be submitted to ADF&G in 2009.

Nelson, S.K. et al. 2008-2010. Marbled Murrelet Habitat Use and Activity Patterns at Port Snettisham, Alaska.
Final Report expected 2010.

Nelson, S.K., B.A. Barbaree, S.H. Newman, H.R. Carter, and D.L. Whitworth. 2008. Marbled Murrelet breeding ecology, terrestrial habitat use, and activity patterns in Port Snettisham, Southeast Alaska, 2005-2007. Unpublished report to the Alaska Department of Fish and Game by Wildlife Trust and Oregon State University. XX pp.
Final Report expected December 2008.

Peery, Z. Adaptive Genetic Diversity of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska compared to other population centers within the species' range.
See Appendix F.

Summary Information—

Alaska Comprehensive Wildlife Conservation Strategy
The Marbled Murrelet is featured in the Alaska Comprehensive Wildlife Conservation Strategy (CWCS). The CWCS can be found online at:
http://www.sf.adfg.state.ak.us/statewide/ngplan/
Information specific to the Marbled Murrelet is in Appendix 4, Pages 211-216 of the CWCS.

Alaska Natural Heritage Program
Summary information for the Marbled Murrelet is available online at the Alaska Natural Heritage Program website. Marbled Murrelet can be selected from this list of birds:
http://aknhp.uaa.alaska.edu/zoology/Zoology_ADFG_birds.htm
Location data can be provided in GIS spatial data format if requested.

APPENDIX A

Abundance, distribution, and decadal trends of Kittlitz's and marbled murrelets and other marine species in Kachemak Bay, Alaska

Kathy J. Kuletz, Elizabeth A. Labunski, and Suzann G. Speckman

U.S. Fish and Wildlife Service
Migratory Bird Management
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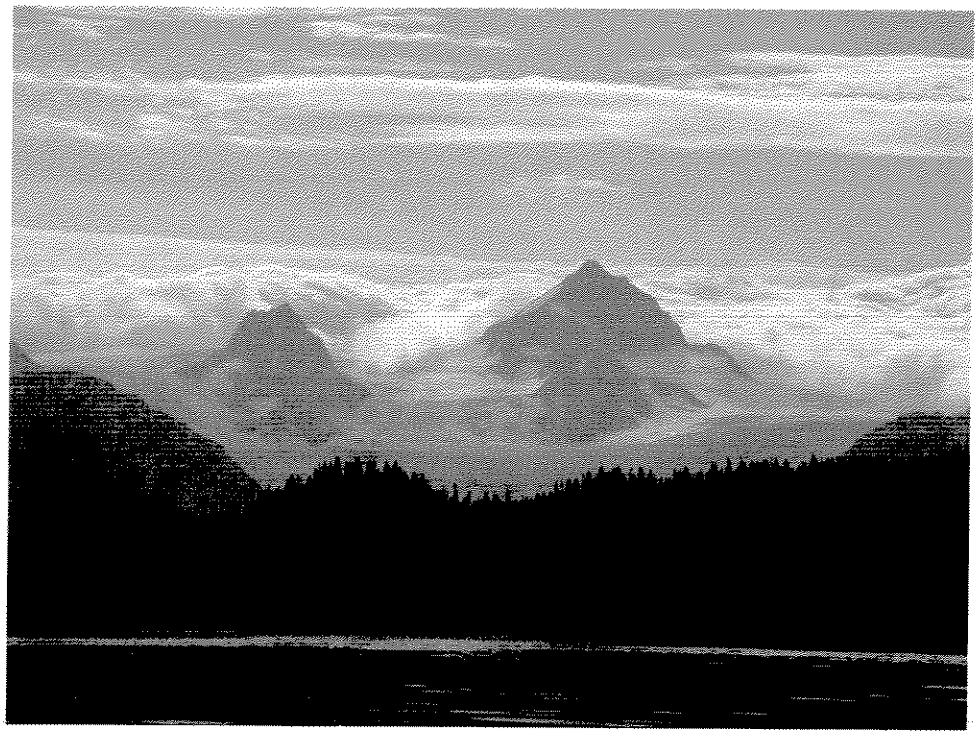

Final Report
June 2008

Suggested Citation:

K.J. Kuletz, E.A. Labunski, and S.G. Speckman. 2008. Abundance, distribution, and decadal trends of Kittlitz's and marbled murrelets and other marine species in Kachemak Bay, Alaska. Final Report (Project No. 14) by U.S. Fish and Wildlife Service for Alaska Department of Fish and Game, State Nongame Wildlife Grant, Anchorage, Alaska.

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EXECUTIVE SUMMARY

The marine avifauna of Kachemak Bay, Alaska, includes breeding populations of two unique species of seabirds, the Kittlitz's murrelet (*Brachyramphus brevirostris*) and the marbled murrelet (*B. marmoratus).* The Kittlitz's murrelet is a candidate species for listing under the Endangered Species Act, and the marbled murrelet is a species of concern in Alaska and is listed as a threatened species south of Alaska. The availability of historic data and the relative accessibility of the Kachemak Bay populations for these two species allowed us to examine decadal trends and patterns of distribution and habitat use. We used boat-based surveys and replicated historic transects where possible to determine population trends and current population size and distribution within Kachemak Bay. Based on the average of point estimates from 2005, 2006 and 2007, the July population was 10,595 (SD ± 964) for marbled murrelets and 1,937 (SD ± 1075) for Kittlitz's murrelets. These numbers were bolstered by an apparent influx of both species into Kachemak Bay in 2006, primarily in the north outer bay south of Anchor Point.

Because of low species identification rates in the 1993 June survey, we examined trends for total *Brachyramphus* murrelet numbers for our 2005 and 2006 June surveys. Between 1993 and 2005, June numbers of *Brachyramphus* murrelets indicated a declined of 32 %, for a per annum rate of – 2.7 %. However, the higher number of murrelets in 2006 resulted in no change in the June population between 1993 and 2005-2006. August surveys indicated that between 1988 – 1999 and 2004 - 2007, densities of Kittlitz's murrelets declined significantly in the inner bay and for the entire bay, the latter by 43 %, or -18 % per annum. Marbled murrelet densities, however, remained stable and even increased in the outer bay, although this difference was not significant.

During the four years of this study (2004-2007), Kittlitz's murrelets were always present in the south inner bay at the confluence of outflow from the Grewingk and Portlock glaciers, which are land locked glaciers. This area was characterized by highly stratified water, with a thin (< 3m) lens of turbid water covering clear water below. The influx of Kittlitz's murrelets to the north outer bay in 2006 coincided with a strong frontal feature that also had turbid water near the surface and clear water below and at the edge of the front, where the murrelets were located. We suggest that although Kittlitz's murrelets are found in water that

is turbid at the surface, a layer of clear water within 5 m of the surface may be an essential feature of their foraging habitat. Further study will be needed to determine the prey and physical parameters that create optimum conditions for murrelet foraging within these types of habitats.

Distribution of marbled murrelets within the bay was broader both spatially and relative to water characteristics, occurring where water was highly stratified and well mixed. Marbled murrelets were primarily found along the south shore of both inner and outer bay, but they also occurred in the north outer bay. Neither species used areas where layers of turbid water extended deeper than ~ 5 - 10 m, and most were in waters < 60 m deep.

Densities of marbled murrelet juveniles (4-year mean = 0.56 ± SD 0.22 birds · km^{-2}) were nearly five times higher than densities of Kittlitz's murrelet juveniles (mean = 0.12 ± 0.12 birds · km^{-2}). However, the ratio of juveniles:adults was comparable or higher for Kittlitz's murrelets. The higher juvenile ratios may be due to the earlier exodus of Kittlitz's murrelet adults compared to marbled murrelets. Alternatively it might reflect a larger proportion of non-breeding marbled murrelets foraging in the bay.

The seasonal patterns of juvenile abundance were different between species. The density of marbled murrelet juveniles increased throughout August, whereas Kittlitz's murrelets appeared later, peaked in mid August, and then disappeared. Marbled murrelet adults also appeared to remain in the bay longer than Kittlitz's murrelet adults, and did not consistently decline in August such as has been observed in Prince William Sound. Our 2004-2007 surveys indicate that the best time to survey for juveniles on the water is generally August 10-23 for marbled murrelets, and August 10-16 for Kittlitz's murrelets. However, because there were inter-annual differences in juvenile temporal patterns, surveys would ideally be conducted 6 – 24 August for both species.

Based on our results, we encourage continued monitoring of the south inner bay for Kittlitz's murrelets and the entire south shore for marbled murrelets. To obtain peak numbers we recommend mid to late July surveys. Although it is logistically more difficult, the north outer bay shelf edge should also be monitored periodically. The periodic influx of murrelets into north outer bay likely came from the Lower Cook Inlet population, and this could be confounding our ability to detect trends for murrelets in Kachemak Bay alone.

Therefore, an extended survey in Lower Cook Inlet, ideally to replicate the 1993 survey, will be needed to gauge the status of the regional population.

Brachyramphus murrelets comprised 15 – 22 % of the total marine birds in Kachemak Bay in July, based on point estimates from our surveys. In July we identified 31 species of marine birds, and of those the only breeding seabird with a population estimate as high or higher than marbled murrelets was the common murre (*Uria aalge*). Sooty shearwaters (*Puffinus griseus*) and smaller numbers of short-tailed shearwaters (*Puffinus tenuirostris*) also had high estimates. The shearwaters breed in the southern hemisphere and visit pelagic waters of Alaska during summer, and their estimates were based on a few sightings of large groups in the outer bay.

In general, the southern shore of Kachemak Bay had the highest densities of all birds, although some species were also abundant in the north outer bay. Other common species in the bay included black-legged kittiwakes (*Rissa tridactyla*), glaucous-winged gulls (*Larus glaucescens*), and pigeon guillemots (*Cepphus Columba*). We did not test for trends in other species, but we suggest such analyses would be useful for management and ecosystem evaluation. Several species may have declined since 1993, including murres, kittiwakes, mew gulls (*Larus canus*), and horned puffins (*Fratercula corniculata*). The most commonly encountered marine mammal was the sea otter (*Enhydra lutris*), for which the mean June estimate for 2005-2006 was 33 % lower than the 1993 point estimate. We also observed harbor seals (*Phoca vitulina*), and occasionally recorded killer whales (*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), Humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*). Distribution and abundance of selected species are provided in figures and tables in the appendix. All survey results were submitted to the North Pacific Pelagic Seabird Database.

INTRODUCTION

The marine avifauna of Kachemak Bay, Alaska, includes breeding populations of two unique species of seabirds, the Kittlitz's murrelet (*Brachyramphus brevirostris*) and the marbled murrelet (*B. marmoratus).* Both species differ from most other seabirds in that they do not nest in colonies, rather they nest dispersed in inland areas, either on old-growth tree branches (marbled murrlelet) or on the ground in rocky, alpine areas (Kittlitz's murrelet). As a result of this nesting behavior it is difficult to monitor their populations and little is known about their reproductive behavior or success. In 2004, population declines of the Kittlitz's murrelet led the U.S. Fish and Wildlife Service to designate it as a candidate species for listing under the Endangered Species Act (69 FR 24875 24904). The marbled murrelet, which is listed as threatened from British Columbia (Burger 2002) to California (McShane et al. 2004), is a species of management concern in Alaska (USFWS 2002, Piatt et al. 2007). Both murrelet species have most of their world population centered in Alaska. The accessibility of Kachemak Bay makes it an ideal location to determine population trends and habitat needs for both species. This project examined decadal trends of these murrelets in Kachemak Bay and determined the current population size and distribution within the bay. Our results lend support to the argument for listing of Kittlitz's murrelets as a threatened species.

The Kittlitz's murrelet is one of the rarest seabirds in North America, and 85 % of the world population is estimated to breed in Alaska (Day et al. 1999, USFWS 2007). Recent surveys indicate severe population declines since the 1980-90's of 75 – 90 %, in Prince William Sound (PWS), Kenai Fjords, Malaspina Forelands, and Glacier Bay (USFWS 2007). Kittlitz's murrelets are typically associated with glaciers, and often forage in the upper portions of fjords with substantial glacial outflow, even among brash ice (Day et al. 1999, 2003). The decline of Kittlitz's in the Gulf of Alaska may be linked to recent changes in coastal glaciers (Kuletz et al. 2003a).

Similar, though less drastic declines have occurred for the marbled murrelet, which is listed as threatened south of Alaska (Piatt et al. 2007). The marbled murrelet is unique among seabirds in its use of old-growth forests for nesting. For marbled murrelets, large-scale changes in breeding habitat have occurred around Kachemak Bay since the 1970's, due

to decimation of forests by spruce bark beetles. Both the rapid recession of coastal glaciers (Arendt et al. 2002), and the unprecedented spread of spruce bark beetles (Berg et al. 2004), are associated with climate change. The occurrence in Kachemak Bay of environmental changes (glacial recession and beetle infestation), coincident with breeding populations of both *Brachyramphus* murrelets, allows us to examine potential population-level effects of climate change on these two upper trophic level species.

Because they do not nest in colonies, *Brachyramphus* murrelets are most readily monitored at sea. In Kachemak Bay, selected transects, primarily along the south shore, were surveyed for marine birds in 1988-89 (Kuletz 1989, 1996), 1993 (Agler et al. 1995) and 1996-99 (Abookire et al. 2000). Most of these projects were directed at the larger scale of Cook Inlet, but they confirmed that Kittlitz's murrelets were often found in the Grewingk Glacier outflow in Kachemak Bay. However, Kittlitz's were also observed in low numbers in other parts of the bay, suggesting that the historic transects provided an incomplete indication of population size for the entire bay. Nonetheless, the historic transects provided a baseline index to examine trends in the murrelet populations over the past decade.

Counts of juveniles at sea are an index of productivity for marbled murrelets (Beissinger and Nur 1997, Kuletz and Kendall 1998, Lougheed et al. 2002), and Kuletz and Piatt (1999) identified 'nursery areas' for juvenile marbled murrelets in Kachemak Bay. The occurrence of juveniles at sea is less well documented for Kittlitz's murrelets, in part because the juvenile plumage for this species has not been well described. Day et al. (2003) found no juvenile Kittlitz's murrelets in several fjords of Prince William Sound, and suggested that the species was not reproducing, perhaps a reason for their population decline. However, juvenile Kittlitz's were reported as occurring in Kachemak Bay during historic surveys (Kuletz 1996 and unpubl. data), and one of the few nests ever located was on a mountain above the bay (Piatt et al. 1999). Thus, Kachemak Bay supports breeding populations of both species, and historic data on juvenile abundance at sea was available for comparison to new data.

The Kachemak Bay population of Kittlitz's murrelet is probably the most readily accessible in the world, yet knowledge of the abundance or trends of Kittlitz's was less known at this bay than at more remote sites. This project collected data on abundance and

distribution of all marine birds and mammals encountered during the surveys, but we focused on four objectives:

Objectives:

- Obtain current population estimates for Kittlitz's murrelets and marbled murrelets in Kachemak Bay.
- Determine decadal trends of Kittlitz's and marbled murrelets in Kachemak Bay.
- Track annual and seasonal patterns of abundance of adult and juvenile Kittlitz's murrelets and marbled murrelets in Kachemak Bay.
- Describe the distribution of murrelets within Kachemak Bay, and identify marine habitats used by murrelets.

In August 2004, this project was launched with support from Ecological Services, U.S. Fish and Wildlife Service (FWS), Anchorage, Alaska. The project was supported in 2005 and 2006 by cooperative agreements with the Division of Wildlife Conservation, Alaska Department of Fish and Game; Migratory Bird Management, FWS; and non-federal match partners (see Acknowledgements). In 2007, a fourth year of July and August data was obtained with support from Migratory Bird Management, FWS.

STUDY AREA

Kachemak Bay is a large bay located northeast of the Kennedy Entrance into Cook Inlet (Fig. 1); the latter is a large tidal estuary that exchanges water with the Gulf of Alaska via the Alaska Coastal Current (ACC). Near Homer, mean tide range is approximately 6 m, with a maximum of 8 m (Schoch and Chenelot 2004). Current velocities range from 3 to 6 knots and are strongly influenced by tidal phase (Okkonen et al. 2007). Kachemak Bay is divided into two basins, referred to as the inner and outer bays, separated by the Homer Spit, which extends 6 km from the north shore. Historically, the areas east of the Homer Spit (on the north shore) and Neptune Bay and extending to Bear Island (on the south shore), were categorized as the inner bay. Areas west of these landmarks extending to Bluff Point (on the north side) and to Point Naskowhak (on the south side) were categorized as the outer bay.

Based on more extensive oceanographic analysis, Speckman et al. (2005) extended the boundary of the inner bay along the south side to Cohen Island.

The inner bay is characterized by higher surface water temperatures, lower salinity levels, and highly stratified layers with high turbidity (Abookire 2000, Schoch and Chenelot 2004, Speckman et al. 2005). These marine features are largely the result of melting snow pack and glacial runoff along the south shore, and river runoff from the Fox River delta at the bay head, which flows westward along the north shore (Fig. 2). Okkonen et al. (2007) provided the most recent, detailed description of hydrography for the study area, which we summarize here. During most months, Kachemak Bay is warmer and fresher than Cook Inlet waters and the confluence of these waters at the bay mouth results in a denser, high-salinity water mass that forms a cyclonic cell and blocks ACC waters from entering the bay. However, cold saline water from the ACC periodically enters the inner basin at depth along the south shore when the differences between water masses is reduced, primarily during late summer and fall months. The outer bay is more directly influenced by the mixing of cold saline waters from the Gulf of Alaska, with periodic pulses of ACC water entering from the south. The predominate currents of the outer bay circle from south to north and do not enter the inner basin (Schoch and Chenelot 2004). As a result, the outer bay is characterized by cold, well-mixed, saline and clear waters. Turnover for water circulation in the bay is approximately one month, with prevailing currents leaving the bay along the north shore, although turbid, fresher water can also enter the northwest region of Kachemak Bay from upper Cook Inlet (Trasky et al. 1977). Ten-year averaged monthly water temperatures at Seldovia, on the outer south shore of the bay, ranged from winter lows of 1.1 to 4.7 ^{0}C, and summer highs of 9.9 to 12.1 ^{0}C (Okkonen et al. 2007). During the four years of our study, surface water temperatures ranged from a low of 4.7^{0}C in April 2005 to a maximum of 16.4^{0}C in August 2007.

Several species of colonially nesting seabirds nest on several islands in Kachemak Bay, with Gull Island having the largest number of nesting birds (Fig. 1). The most abundant colonial birds are black-legged kittiwakes (*Rissa tridactyla*) and common murres (*Uria aalge*). Other common species at the colonies include tufted puffin (*Fratercula arctica*) , pelagic cormorant (*Phalacrocorax pelagicus*), glaucous-winged gull (*Larus glaucescens*), and pigeon guillemots (*Cepphus columba*), and a variety of species in smaller numbers.

METHODS

To meet our objectives, our four main approaches were: 1) To obtain current population estimates, we designed a systematic survey of the entire bay during peak murrelet abundance in mid-July. 2) We examined population trends by replicating historic surveys, which occurred June through August. 3) From a compilation of all surveys we outlined seasonal patterns of abundance for both murrelet species, in particular the occurrence of juveniles on the water. 4) We mapped current distribution of murrelets within the bay, and used associated habitat characteristics to describe marine habitat use by murrelets.

Sampling Design

Historical data from Kachemak Bay were provided by the U.S. Fish and Wildlife Service (K. Kuletz), or the U.S. Geological Survey, Alaska Science Center (J. Piatt and S. Speckman). Data collected from 1988 to 1993 consisted of total numbers of birds counted along each transect. Transect end points for historic surveys were generally defined by major landmarks. Data collected since 1995 were GIS-based, so that each sighting is associated with a latitude and longitude. The majority of surveys in Kachemak Bay were conducted from 8-m Boston whalers, using two observers and a driver. All available data resulted from strip transect surveys, but transect widths ranged from 200m to 1000m (the latter in 1988 only). The 2004-2007 surveys were consistent in platform, protocol, and primary observers. The June set of transects were randomly selected (Agler et al. 1995), but selection was from a grid for a larger Lower Cook Inlet survey. Except for the July comprehensive surveys, the 2004-2007 surveys were designed to replicate transects and survey dates from the most complete historic surveys.

Population Estimates

Brachyramphus murrelet abundance shows strong seasonal patterns, making it imperative to compare data collected during similar time periods (Kuletz and Kendall 1998, Kuletz et al. 2003b). There were no historic surveys that covered all portions of the bay during mid July, which is typically a period of peak murrelet abundance in Alaska's nearshore waters (Kuletz and Kendall 1998, Speckman et al. 2004). Furthermore, the 1993 June set of transects did not adequately cover the inner bay. In particular, few transects fell in the south inner bay. Therefore, to obtain a current population estimate and establish a

baseline for future comparisons, we designed a July survey consisting of systematic transect lines throughout the bay at 4 km intervals (Fig. 3). These lines were selected by extending the same north-south longitude lines from a grid used to randomly select the 1993 FWS transects. To avoid over-sampling shoreline habitat in a bay with highly convoluted shoreline (G. Drew, unpublished data, USGS, Anchorage, Alaska), we did not include a shoreline strata, but did record birds in the zone from 0 - 200 m off shore separately, to accommodate future stratification. The July survey was comprised of twelve transects, which as measured from the GPS-derived track lines varied slightly among years (due to tide or weather effects on the boat's movements), and totaled approximately 188 km (38 km^2) each year.

Population Trends

For analysis of decadal population trends, we used two time periods – mid June (incubation period), and 25 July to 18 August (late chick-rearing and fledging period). The June surveys included one historic survey from 1993 and our recent surveys in 2005 and 2006. June surveys were comprised of transects within Kachemak Bay that were part of a 1993 FWS survey of Lower Cook Inlet (Agler et al. 1994), and included randomly selected transects from two strata: shoreline and pelagic. Because these were randomly selected transects we were able to estimate population size in addition to calculating densities. The June survey was comprised of 46 transects (Fig. 4) for a total of 166 km (33.3 km^2). Individual transect identification numbers are available in Appendix A-1.

We defined the late summer time period (25 July – 18 August) by making a preliminary examination of the seasonal changes in murrelet abundance from all available surveys. Surveys earlier than 25 July had variable and high numbers of murrelets, and after 18 August numbers declined quickly. The late summer surveys were divided into three regional strata, the inner bay, south outer bay, and north outer bay. These transects had been designed in the past to monitor abundance patterns and juvenile murrelet occurrence, and thus were established to optimize murrelet encounters (Kuletz 1989, Kuletz and Piatt 1999). The historic transects roughly paralleled the shoreline or zigzagged between shore and mid-bay, and used topographic features to delineate transect end points (Fig. 5A). Because these transects were not randomly or systematically selected they could not be used to derive

population estimates, but could be used to compare murrelet densities (birds • km^{-2}). To analyze population trends during the murrelet fledging period, we considered a sample to be a set of transects in the same strata that could be surveyed in one day (hereafter, Transect Set). There were six late summer Transect Sets (Fig. 5B), with two in the inner bay – Inner South Shore and the Inner Zigzag, three in the south outer bay – Outer Zigzag, Outer South Shore, and Eldredge Passage, and one in the outer north bay – Outer North Shore. Individual transect identification numbers are shown in Appendix A-2.

Seasonal Patterns, Chronology, Productivity

We conducted surveys during April, June, July, August, and September for a total of 86 survey days over four years (Table 1). We used all surveys conducted from 2004 through 2007 to describe the seasonal patterns and chronology of both murrelet species. The most complete seasonal data within a given year was obtained in 2005. Data from that year describes seasonal patterns from April to September. In addition, murrelet occurrence in lower Cook Inlet was documented in September and October of 2005, in collaboration with oceanographic surveys by Dr. S. Pegau (Kachemak Bay National Estuarine Research Reserve). The Cook Inlet survey track lines were run opportunistically as the vessel transited among Homer harbor, the Barren Islands, Shuyak Island, Cape Douglas, Chinitna Bay, and Anchor Point.

Marine Habitat Use

We identified critical habitats for Kittlitz's and marbled murrelets in Kachemak Bay by combining at sea surveys with GIS bathymetric coverages and concurrent CTD sampling of the water column. Water column profiles and bathymetric data were used to describe marine features associated with areas of high murrelet density. Murrelet observations were mapped using ArcView GIS (ESRI, Redlands, CA). Habitat maps and satellite imagery were provided by the Kachemak Bay Research Reserve (primarily marine) and the Kenai Peninsula Borough Spruce Bark Beetle Mitigation Program.

At-sea Survey Protocol

The June survey took 4 - 5 days (depending on weather) and was done once each year (1993, 2005, 2006) between 16 - 20 June. The July survey took 4 - 6 days and also occurred once each year (2005-2007), between 18 - 25 July (Table 1). The late summer surveys of the six Transect Sets were conducted in 2004-2007 between 1 - 23 August. The number of survey days varied among years, with 2007 having the fewest survey days (Table 1). We used historic late summer surveys that were conducted between 25 July and 18 August. Each late summer Transect Set was surveyed 1 - 5 times each year (1988, 1990, 1995 – 1999, 2004-2007). We alternated survey days between inner and outer bays to reduce autocorrelation and bias from seasonal changes in murrelet abundance. Transect Sets with multiple surveys in a given year were typically spaced at 3 - 8 day intervals. To obtain information on seasonal patterns of murrelet abundance, in 2005 we conducted several surveys ancillary to the ones used for population estimates and trends. We surveyed a subset of the Inner South Shore transects (no. 8801 - 8804) on 24 April, 20 June, 24 July, and 2 September. We also surveyed the Eldredge Passage Transects Sets on those dates, with the exception of 20 June.

Surveys were conducted from an 8-m fiberglass boat traveling approximately 10-20 km • hour^{-1}, with observers using standard USFWS strip transect protocol (Kendall and Agler 1998) with some modifications to accommodate murrelet surveys (Appendix B-1). Surveys were conducted between 0700 and 1700 hours, by crews consisting of two observers and one boat driver. Two observers stood on opposite sides of the boat and used 10x42 binoculars to record all birds and mammals observed within 100 m of the boat. Species' behavior at the time of the observation was recorded as on water, in air, on land, foraging, or in a forage flock. We considered murrelets to be actively foraging if they were observed forage diving (crouched in a deep-dive position and subsequently diving, with a different behavior from avoidance diving), associated with a feeding flock, chasing fish to the surface, or bringing fish to the surface. Observations of birds holding fish were used to determine diet when possible and as an indication of chick-feeding activity. All vessels (boats and kayaks) present on transect were recorded, and vessels within 100 - 500 m of the transect line were recorded as present but off transect.

We used GIS to incorporate the historic and the new July track lines into the DLOG program (R.G. Ford, Inc., Portland, OR), and then used the vessel's navigation system to follow those lines during surveys. The observers entered sightings directly into a laptop computer using DLOG survey software and integrated with a Global Positioning System (GPS). The system logged an associated latitude and longitude for each recorded observation, and automatically wrote to record location data at 20 second intervals to track our effort. DLOG allowed us to map precise locations of observed birds for *post hoc* analysis of habitat use, but we continued to record historic transect reference numbers to allow comparisons for the decadal trends component. Occasional deviation from the transect route was necessary for murrelet identification, or more commonly during late summer surveys, for age-class confirmation. When this occurred we ceased survey effort, entered a waypoint into the navigation system, and went off transect to get a better look at the bird. The distance traveled during this time was not included in the transect route used later to calculate birds • km^{-2}. After age class or identification was confirmed, the vessel would return to the waypoint and we resumed surveying "on transect" (see Appendix B-1).

We recorded all birds and mammals encountered on the transect, and recorded as off transect any unusual sightings (i.e., rare species of birds or mammals, or large groups). Off-transect sightings were not included in density calculations but were used for mapping distribution of rare species. For each murrelet or murrelet group we also recorded the bird's estimated distance from the boat in 25 m incremental bins, plumage class, age category, and group size.

Juvenile identification – Observers were trained to distinguish after-hatch-year birds, heareafter referred to as 'adults', and hatch-year birds, hereafter referred to as 'juveniles'. Thus, for this report adults include an unknown proportion of immature birds (approximately 1-3 years old; Day et al. 1999), which can not be distinguished in the field from mature, breeding age birds. We used established identification criteria for marbled murrelet juveniles (Carter and Stein 1995, Kuletz and Kendall 1998), and also developed photographic field guides to assist observers (Appendix B-2). There was little information available on identification of Kittlitz's murrelet juveniles. To enable this and future surveys to identify juvenile Kittlitz's murrelets we made extensive visual observations of suspected juveniles.

We also examined study skins and photographs taken of known Kittlitz's murrelet chicks and fledglings, and developed photographic field guides for this species (Appendix B-2).

Ancillary Surveys

Lower Cook Inlet Surveys. -- One observer stationed on the bridge of the *F/V Columbia* surveyed for marine birds and mammals using standard FWS protocol and entered observations into a laptop equipped with DLOG and GPS. This vessel was larger than our standard platform (approximately 14 m in length and 4 m above the water), so the observer counted all birds and mammals within 150 m of one side (port) of the vessel. We used ArcGIS to plot observations (Appendix D).

Nighttime activity. -- On August 23, 2004 between 2230 and 0500 hours we used a spotlight to search for murrelets at night. We covered an area where we had observed high densities of adult and juvenile Kittlitz's during our daily surveys. From Glacier Spit to Aurora Lagoon we traveled parallel to the shoreline at 100 m and 200 m off shore in a zigzag pattern.

Inland juvenile search. -- Russian scientists have suggested that newly fledged Kittlitz's murrelets fledge to upland glacial lakes, which may explain low encounter rates of juvenile birds at sea early in the fledging period (T. Van Pelt, pers. comm.). To explore this possibility we hiked to the most likely and accessible lake in Kachemak Bay during a time when fledging should have begun. We were ferried between the Homer boat harbor and Glacier Spit on the south side by one of our project partners, Cook Inlet Keeper. During 25 – 26 July 2005, we conducted a land-based recognizance survey of Grewingk Glacier Lake, 4 km inland of the Grewingk Glacier outflow into Kachemak Bay. Four observers spent two days canvassing the area with spotting scopes and binoculars.

Marine Habitat Use

Survey Conditions and Environmental Data -- Environmental variables were recorded at the start of each transect, and at pre-selected intervals during long transects. We recorded start time, weather and sea conditions, water clarity (Secchi disk), surface salinity, sea surface temperature (Salinity meter), wind speed (Kestrel wind gauge) and air temperature, and overall observation conditions.

Hydrographic surveys.- During the June and July surveys we conducted hydrographic surveys using a CTD (Conductivity-Temperature-Depth) probe (Seabird Electronics Inc., SBE 19 SEACAT), fitted with an additional sensor to measure turbidity. Sampling effort for the CTD varied among years and months. Immediately following the June surveys of 2005 and 2006 we sampled a line of 11 CTD stations, at 4 km intervals, running east-west down the middle of the bay (Fig. 6). Following the July surveys in 2005 and 2006 we sampled 9 lines running north-south, at roughly 4 km intervals, for a total of 32 stations. In 2007 we sampled 3 north-south lines, two in the inner bay and one in the outer bay (Fig. 6). Dr. Scott Pegau of the Kachemak Bay National Estuarine Research Reserve also provided us with his CTD data. He sampled a line, referred to as the Barabara line, which ran across the outer bay from Bluff Point on the north to Barabara Point on the south (Fig. 6). The Barabara line was sampled in June and July of 2005 and July and August of 2006. Stations were spaced 1 nautical mile (nm) apart; the closer spacing of sample stations provided a more detailed water profile. The CTD used for the Barabara line included an ancillary flourometer sensor, which provided an indication of chlorophyll *a*, and thus of primary productivity. We also sampled the Barabara line using Dr. Pegau's stations in July 2007, but did not have access to a flourometer.

We used the vessel's navigation system to locate each station and record a depth reading. The CTD was flushed with distilled water and a 10 km weight tied to a 1 m line at the end to reduce flagging of the CTD in the currents. Before lowering the CTD it soaked for 1 min at 1 m below surface. We then lowered the CTD at approximately half meter a second until it reached a depth 5 – 10 m from bottom, or it reached 200 m. A mechanical winch was used to maintain a steady lowering and raising speed. Data from the CTD was downloaded onsite and processed later by Dr. Scott Pegau and E. Labunski.

Data analysis

Population Estimates

We used ArcGIS software to analyze daily track lines to calculate the kilometers traveled, which resulted in slight variations in transect lengths among surveys of the same lines. Daily transect lengths were multiplied by transect width (0.2 km) and converted to km^2, and these area values were used to calculate bird densities (birds • km^{-2}). We present

densities and numbers of birds for marbled murrelets, Kittlitz's murrelets, unidentified *Brachyramphus* murrelets and total *Brachyramphus* murrelets. The July transects bisected several seabird colony islands, and we did not have time to do a complete census of colonially nesting birds. The seabirds rafting and flying near the colonies skewed the at-sea counts. For the July survey only, we therefore used GIS to create a 400 m radius buffer around the colonies in the Gull Island complex and Sixty Foot Rock, and did not include birds within that buffer in our transect density calculations.

The study areas used to extrapolate densities to population estimates were separated using ArcGIS between inner and outer bay areas (Fig 4). Because the June surveys replicated the two strata used for the 1993 surveys, for the June surveys we also used ArcGIS to separate areas into a 200 m buffered shoreline strata and a pelagic strata. The shoreline strata included waters 0-200 m from shore (total of 57.84 km^2) and pelagic strata were waters >200 m from shore (total of 742.79 km^2).

The areas used to extrapolate bird densities to population estimates totaled 815.64 km^2 for all of Kachemak Bay, with 315.9 km^2 in the inner bay and 499.74 km^2 in the outer bay. For the June data we used a ratio estimator to estimate population sizes and variances for each stratum (shoreline and offshore) and for inner, outer, and entire bay. For each region, we summed the estimates of the strata, and added the variances of the estimates to obtain 95% confidence intervals (Cochran 1977). For July surveys we did not stratify habitats, and included all waters to shoreline. We again used a ratio estimator to estimate population sizes, and variances reflect spatial variation in bird densities among 12 transects. We estimated both June and July population sizes with and without flying birds. For June we present estimates using all birds, to insure the best comparison with 1993 data. For July we present estimates for murrelets both with and without flying birds.

Population Trends

We minimized seasonal variability in counts by limiting data analysis to the same time window for any given set of transects. Analysis of these congeneric murrelets is complicated by the fact that they are difficult to separate in the field. The proportion of birds that fell into the unidentified category tended to decline in later years. This trend in species identification can confound detection of species-specific population trends. We therefore analyzed trends

for four species groups: Kittlitz's murrelets, marbled murrelets, unidentified *Brachyramphus* (birds identified only to genus), and total *Brachyramphus* murrelets (identified and unidentified combined).

For the late summer changes in population trends we could only examine murrelet densities. Changes in murrelet density over time were modeled with least-squares linear regression. The slope of the regression was tested for a significant deviation from zero at the alpha 0.05 significance level, indicating either a positive or negative significant change. Changes in density over time were modeled as the natural logarithm of that year's count converted to a percentage of the initial or first year's count (R. Stehn, USFWS, pers. comm.). The slope of a least-squares linear regression through the transformed counts is the growth constant (positive slopes) or the decay constant (negative slopes). The slopes of these regressions were also tested for significant deviations from zero at the alpha 0.05 significance level. The per-annum percent change in the population (indexed by the density) was derived from the back-transformed best-fit slope of the regression (R. Stehn, pers. comm.).

Trends analyses were performed for each Transect Set in Kachemak Bay, 1988 - 2007 for surveys conducted between 25 July and 18 August. The analyses were done for all murrelet categories except Kittlitz's murrelets in the outer bay; only a few Kittlitz's (0 - 2 % of total Kittlitz's) occurred in the outer bay and a single sighting in a given year skewed analyses, thus a test of Kittlitz's murrelet trends in the outer bay would not be statistically valid or biologically meaningful. We also compared murrelet densities between two decadal time periods, 1988-1999 (historic) and 2004-2007 (recent). We tested for differences in murrelet densities between time periods with a Wilcoxon Rank Sum test, and we did this for the entire bay and for the inner and outer bay regions separately.

Archiving of survey data. -- All survey data were prepared and formatted for entry into the North Pacific Pelagic Seabird Database (NPPSD; USFWS, Anchorage). To complete this task, we contracted with Dr. M. Renner (University of Washington, Seattle) who developed a conversion program in 'R'. For preparation for the NPPSD, our survey lines and observations were binned into transect lengths of 3 km. We also ran the program to bin observations into 1 km lengths for future fine-scale analyses.

Seasonal Patterns, Chronology, and Productivity

Seasonal changes in murrelet density or population estimates were graphed to examine temporal patterns of murrelets in Kachemak Bay. For both adult and juvenile murrelets, we standardized daily densities during late summer as a proportion of the year's maximum density, graphed over time, and separated into inner and outer bay regions. The numbers of birds holding fish, indicative of chick-rearing, were graphed by weekly time periods, using the combined observations from 2004-2007.

Productivity indices were obtained from the densities of juveniles observed on late summer transects, and the ratios of juvenile:adult murrelets (hereafter, juvenile ratios) during a day's survey. We used the juvenile murrelet density from each survey day to test for differences among years and regions. We tested for differences in juvenile densities and juvenile ratios among years and regions (inner vs outer bay) with ANOVA, with alpha = 0.05 as significant.

Marine Habitat Use

Data from the CTD was processed using standard SeaBird processing alogorithms by Dr. Pegau (details in Okkonen et al. 2007). The station location, date, time, water depth, and associated data were used to plot the data on conductivity, temperature, and density throughout the water column. The final analysis provided water profiles for temperature (^{0}C), salinity (psu), and an index of turbidity. Turbidity is shown as Obs[V], based on transmissometer voltage (tran[v]), or as c650[/*m*], which is calculated from the tran[v] to calibrate between different instruments; the two values use different scales, so the magnitudes can not be compared, however the patterns of turbidity that they depict are comparable. The Barabara line also included productivity as indexed by fluorescence (fluor[V]). To describe the hydrography of our study areas for this report, we used the lines with the best resolution, multiple sampling periods or years, and lines that ran across areas with both high and low murrelet densities. The selected lines included July sampling of lines 2 and 3 in the inner bay, and in the outer bay, line 12 and the Barabara line (Fig. 6). Data from the remaining stations was archived for future fine-scale analyses.

RESULTS

Results for Other Species

June and July population estimates for all species encountered are presented in Appendix E-1 and E-2, respectively. Distribution maps for selected species or species groups in July are presented in Appendix F. For the more abundant species, we mapped the results of the July 2006 survey as representative of species distribution. For less abundant species we present all three years of July surveys, or include multiple species for 2006 only. The complete data set will be archived in the NPPSD.

In June we recorded 34 identified species of birds and 3 species of marine mammals (Appendix E-1). Common murres (*Uria aalge*), marbled murrelets, black-legged kittiwakes (*Rissa tridactyla*), and glaucous-winged gulls (*Larus glaucescens*) were the most abundant species in June, although there were a few groups of sooty shearwaters (*Puffinus griseus*) in the outer bay that resulted in high population estimates for this visitor from the southern hemisphere.

Brachyramphus murrelets comprised 15 – 22 % of the total marine birds in Kachemak Bay in July, based on point estimates from our surveys. In July we identified 31 species of marine birds and 4 species of marine mammals (Appendix E-2). Of identified birds, the only breeding seabird with a population estimate as high or higher than marbled murrelets was the common murre. Sooty shearwaters and smaller numbers of short-tailed shearwaters (*P. tenuirostris*) also had high estimates, but these were based on a few large groups. In general, the southern shore of Kachemak Bay had the highest densities of all birds, although some species were also abundant in the north outer bay. The north side of the inner bay was mostly devoid of birds except near the Homer Spit. Other common species in July included black-legged kittiwakes, glaucous-winged gulls, and pigeon guillemots (*Cepphus columba*).

We did not test for trends in June populations for species other than murrelets, but the population estimates suggested that several species may have declined since 1993, including murres, kittiwakes, mew gulls (*Larus canus*), and horned puffins (*Fratercula corniculata*). The most commonly encountered marine mammal was the sea otter (*Enhydra lutris*), for which the mean June estimate for 2005-2006 was 33 % lower than the 1993 point estimate. We also observed harbor seals (*Phoca vitulina*), and occasionally recorded killer whales

(*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), Humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*).

Results for *Brachyramphus* murrelets

During our 2005-2006 June surveys we counted 237 murrelets 'on transect', of which Kittlitz's were 0 – 4 %, marbled murrelets were 100 - 92 %, and unidentified *Brachyramphus* were 0 – 4 % (2005 and 2006, respectively). During the 2005-2007 July surveys we counted 2,057 murrelets, with Kittlitz's ranging 9 – 21 % of the total, marbled murrelets ranging 74 – 82 %, and unidentified *Brachyramphus* ranging 5 – 11 % (mean = 6.3 %). During the 2004 - 2007August surveys we counted 12,676 murrelets on transect, with unidentified *Brachyramphus* comprising between 3 % (2006) and 10 % (2004) of total murrelets. In August, Kittlitz's murrelets ranged from 4 to 24 % of total murrelets and marbled murrelets ranged from 73 to 85 % of total murrelets. See Appendix C for murrelet densities on individual transects.

Current Population Estimates

June. -- Population estimates were higher for both murrelet species in June of 2006 than in June 2005 (Table 2). No Kittlitz's murrelets were observed during the June 2005 survey, but 8 were observed during the June 2006 survey, which resulted in a population estimate in 2006 of 319 ± 435 95% CI. The marbled murrelet population in June was estimated at 3,651 ± 1823 in 2005 and 7,312 ± 4376 in 2006. For both species, over 96 % of the estimated population occurred in waters > 200 m from shore; only 1 % of marbled murrelets and 2 – 4 % of Kittlitz's murrelets were in the 'shoreline' strata. In 2005 and 2006 the estimated population of marbled murrelets was greater in the outer bay than in the inner bay, whereas Kittlitz's murrelets were entirely in the inner bay in June (Table 2). Note that the inner and outer bay population estimates were not exactly the same as the estimates derived from applying densities of all transects to the area of the entire bay.

July. -- For both murrelet species, the highest population estimate was obtained in July (Table 3). The marbled murrelet population in July declined each year between 2005 and 2007, although the decline was not statistically significant. The July population of Kittlitz's murrelets was highest in 2006 and lowest in 2007 (Table 3). The maximum population size

(without flying birds) was estimated at 11,355 ± 4546 95% CI for marbled murrelets in 2005 and 3,108 ± 2932 for Kittlitz's murrelets in 2006. Based on the annual point estimates, the average July population estimate over three years (2005-2007) was 10,595 (SD ± 964) for marbled murrelets and 1,937 (SD ± 1075) for Kittlitz's murrelets.

Population Trends

Trends in Murrelet Population Estimates

June surveys indicated a decline in total *Brachyramphus* murrelets of 32 % between 1993 and 2005, a per annum decrease of -2.7 %. However, the 2006 population estimate was higher than in 1993 (Table 2), and there was no change in trend for total *Brachyramphus* murrelets from 1993 to the 2005-2006 estimates.

For July population estimates we found no significant trends between 2005 and 2007, although the 2007 estimate was the lowest among these three years for both murrelet species (Table 3). The 2007 estimate for marbled murrelets was 84 % of the highest estimate in 2005, and the Kittlitz's murrelet estimate was only 32 % of the 2006 estimate.

Trends in Murrelet Densities

Compared to historic late-summer murrelet densities, the August 2004-2007 densities declined for Kittlitz's murrelets in the inner bay (Inner South Shore and Inner Zigzag Transect Sets), but increased or remained stable for marbled murrelets (Fig. 7A&B). The increase in marbled murrelets is significant in the Inner South Shore Transect Set, but this is concurrent with a significant decrease in unidentified murrelets (Fig. 7A). Because marbled murrelets were always numerically dominant, most unidentified murrelets were likely marbled murrelets, and because identification of species improved over time, results must be examined in conjunction with results for unidentified murrelets and total *Brachyramphus* murrelets. The apparent increase in marbled murrelets is likely an artifact of the much higher percentage of unidentified *Brachyramphus* murrelets in historic surveys. Total *Brachyramphus* densities in August showed no trend in the Inner South Shore (Fig 7A). In the outer bay, marbled murrelets and total murrelets increased, but not significantly (Fig. 7C&D). For identified murrelets, the highest per annum change was -18 % for Kittlitz's murrelets in the inner bay (Fig. 7B, Inner Zigzag). The highest per annum changes for total

Brachyramphus murrelets were a -6 % decline per year in Eldredge Passage (7E), and a 6 to 8 % increase per annum in the north and south outer bay (Fig. 7C,D,F).

In summary, for identified murrelets during August surveys, in the inner bay Kittlitz's murrelets declined and marbled murrelets increased or remained stable (Table 4). Total *Brachyramphus* remained stable or declined in the inner bay and in Eldredge Passage area, but increased in the outer bay (Table 4). The only statistically significant trend was the increase in marbled murrelets in the Inner South Shore, but this was confounded by the significant decrease in unidentified murrelets.

Between the two decadal periods (1988-1999 and 2004-2007), Kittlitz's murrelet densities declined significantly in the inner bay and in the entire bay (Table 5). For the entire bay, Kittlitz's densities declined by 43 % and in the inner bay 20 % between decadal periods. Total *Brachyramphus* densities increased significantly in the outer bay, however, murrelet densities in the outer bay were never > 20 % of densities in the inner bay (Table 5), and the change in densities for the entire bay was not statistically significant. The apparent increase in marbled murrelet densities is, again, likely due to the concurrent decline in unidentified *Brachyramphus* as identification rates improved over time.

Seasonal Patterns, Chronology, and Productivity

Seasonal Patterns of Abundance

Based on the 2005 surveys of selected south shore transects, both murrelet species were present but in very low numbers in April (Fig. 8). During the April survey we recorded only two Kittlitz's murrelets in basic (winter) plumage, and six marbled murrelets in basic or transitional plumage. Murrelet densities increased in June (except for Kittlitz's murrelet in 2005), peaked in late July, and declined by mid August (Fig. 9). By mid-June, there was little change in abundance of Kittlitz's murrelets, but marbled murrelets had increased to roughly half of their peak July numbers. In July marbled murrelets reached a density of 32.14 birds • km^{-2} in the inner bay and 44.80 birds • km^{-2} in the outer bay. Peak Kittlitz's murrelet densities also occurred in late July, at 10.71 birds • km^{-2} in the inner bay. Kittlitz's were not recorded in the outer bay during the 2005 surveys. Both species declined by nearly half by mid August. By early September, only a few Kittlitz's murrelets were recorded (0.24

birds • km^{-2} in the inner bay) and densities of marbled murrelets were lower than in June, with 8.63 and 2.73 birds • km^{-2} in the inner and outer bay, respectively.

We found a similar seasonal pattern in the densities recorded during the more comprehensive population surveys in June and July, and the August surveys of 2004-2007. Densities of both murrelet species increased between mid June (Table 2) and late July (Table 3), and then decreased in August (Table 4 and Appendix C). Kittlitz's murrelets were either not present or occurred in low numbers in June, whereas marbled murrelet densities were comparatively high by June.

Adult patterns of abundance in August. -- We were able to examine changes in murrelet densities throughout August in more detail because of the more intensive survey effort during the murrelet fledging period. In August, adult Kittlitz's murrelets (Fig. 10), were almost exclusively in the south inner bay, and they peaked around 10 August and declined abruptly after 16 August (with a less abrupt decline in 2005). In contrast, changes in marbled murrelet numbers during August varied among years, with peak numbers ranging from early August (in 2005) to mid August (in 2004). In general, marbled murrelets also had less drastic declines in late August (Fig. 10). Marbled murrelet densities were always greater in the inner bay, and their presence in the outer bay during August was highly variable, ranging from 66.69 birds • km^{-2} (4 August 2004) to 1.64 birds • km^{-2} (22 August 2005). Marbled murrelets showed no clear pattern of increasing or decreasing in the outer bay during August; in 2005 and 2007, numbers generally increased with date, whereas in 2004 and 2006, their numbers generally decreased with date (Fig. 10).

Murrelet Chronology

Between 2004 and 2007, observations of birds holding fish, indicative of chick rearing, were recorded during surveys on 28 and 56 occasions for Kittlitz's and marbled murrelets, respectively. Of these, two of the Kittlitz's and three of the marbled murrelets were juveniles feeding themselves. Omitting the juvenile birds, the number of birds holding fish was high throughout the first half of August, after which only 7 marbled murrelets and no Kittlitz's murrelets were observed holding fish (Fig. 11). The first observation of fish-holding was 19 and 20 July for marbled and Kittlitz's murrelets, respectively. The last observation of fish-

holding was 16 and 23 August for Kittlitz's and marbled murrelets, respectively, but August 23 was our latest survey date.

Our earliest observations of newly fledged marbled murrelets were between 2 and 8 of August, but the late sighting was also our first late summer survey in 2007. The density of marbled murrelet juveniles in August ranged from a high mean of 0.79 (SE ± 0.21) birds • km^{-2} in 2004 to a low mean of 0.27 (SE ± 0.06) in 2007. Among years there was no clear pattern in the occurrence of juvenile marbled murrelet densities, with peak densities recorded as early as 7 August and as late as 23 August (Fig. 12). The earliest observation of juvenile Kittlitz's murrelets was 5 August and peak juvenile densities occurred between 8 and 16 August (Fig. 12).

Because of the low numbers of juveniles and the lack of a strong pattern within years for both species, we combined observations for all four years (August surveys of 2004-2007) and examined seasonal patterns of juvenile abundance in 5-day periods (except for the last period, which included only 3 days; Fig. 13). At this coarser temporal scale, marbled murrelet juveniles show increasing densities throughout August, with the highest densities occurring August 21-23. Kittlitz's murrelet juveniles show a very different pattern, with very low densities before 10 August, a pronounced peak in 11-15 August, and a rapid drop off of juveniles afterwards (Fig. 13).

Murrelet Productivity Indices

Mean annual marbled murrelet juvenile densities were nearly five times, and significantly higher, than those of Kittlitz's murrelets (Wilcoxon Rank Sum test; $Z = -6.9254$, $P = 0.001$). However, juvenile:adult ratios were comparable or even higher for Kittlitz's murrelets (Table 6). When juvenile densities were tested as a function of year and region (inner vs. outer bay), only region showed significant differences. Marbled murrelet juvenile density was significantly higher in the outer bay (ANOVA; $F_{1,63} = 11.86$, $P = 0.0010$). Kittlitz's murrelet juvenile density approached significance, with higher densities in the inner bay, but more variance (ANOVA; $F_{1,63} = 3.36$, $P = 0.071$).

For marbled murrelets, annual mean juvenile density was highest in 2004 and lowest in 2007 (Fig. 14). For Kittlitz's murrelets, juvenile density was highest in 2006 and lowest in 2005, with a pattern of alternating years (Fig. 14). For Kittlitz's murrelets, juvenile:adult

ratios were extremely low in 2006 and relatively high in 2007 (Fig. 14). Marbled murrelet juvenile:adult ratios did not vary as drastically among years, and were highest in 2006 and lowest in 2007 (Fig. 14).

Distribution and Marine Habitat Use

Adult Distribution

In April, the few murrelets observed during surveys along the south shore occurred primarily in the inner bay, although one marbled murrelet was recorded near Hesketh Island (Fig. 8). In June, marbled murrelets were distributed throughout the bay, but were absent from most of the shoreline and mid-bay transects in both years (Fig. 15A,B). No Kittlitz's murrelets were recorded in June 2005, and the few Kittlitz's observed in June 2006 were offshore in the inner bay and in Halibut Cove Lagoon (Fig. 15C).

During the more comprehensive July surveys, marbled murrelets were generally found throughout the inner bay east of Halibut Cove, and in the outer bay in the Eldredge Passage area (especially in 2007) as well as across the bay mouth (Fig. 16). In all years, particularly in 2007, few marbled murrelets were observed in the center and deepest part of the bay, an area roughly 4 km east of and 12 km west of the Homer Spit. Kittlitz's murrelets were more restricted in distribution (Fig. 17), and in July of 2005 and 2007, nearly all Kittlitz's were observed on just three transects in the inner bay between Glacier Spit and Bear Cove. In contrast, in 2006 Kittlitz's murrelets were observed on these same transects, but also in the north outer bay. For all three July surveys combined, approximately 98 % of all Kittlitz's murrelets were found within these two 'hot spots'. The hot spot in the south inner bay was approximately 75 km^2, and included the deeper waters of the inner bay, which were < 20-60 m deep (Fig. 18). The outer bay hot spot (at least in 2006), was approximately 128 km^2 and included the more shallow waters of the outer bay, approximately 20-40 m deep (Fig. 18). In 2007, Kittlitz's murrelets were highly aggregated from shore to < 2 km off of Aurora Lagoon, in water 20-60 m deep (Fig. 17, 18).

Between 2005 and 2007, the (non-significant) decline in marbled murrelets was primarily evident in the much lower numbers in the inner bay in 2006 and 2007, concurrent with slight increases in the outer bay (Fig. 19). The Kittlitz's murrelet population was highest in 2006, due almost entirely to an increase in the outer bay (Fig. 19).

During August, surveys were primarily conducted in the southern half of the bay, with the exception of two transects along the north outer shore. August patterns of distribution were consistent among years. As an example, in August, 2005, marbled murrelets were found throughout the inner and outer bay, including the north outer transects (Fig. 20). During the same surveys, Kittlitz's murrelets were almost exclusively in the south inner bay (Fig. 20), showing a distribution similar to what we observed in June of that year.

During the ancillary surveys conducted in Lower Cook Inlet, we found low murrelet abundance in September and October of 2005. In September, marbled murrelets were observed in the north outer bay and to a lesser extent off of Anchor Point (Appendix D), with densities of up to 3.59 birds · km^{-2} (Appendix E-3). Murrelets were also observed on the south side of the bay mouth near Port Graham, with densities of up to 1.40 birds · km^{-2}. In October, fewer murrelets were recorded off of Anchor Point (Appendix D), with a total *Brachyramphus* density of 0.89 birds · km^{-2} for that area (Appendix E-3). We did not observe *Brachyramphus* murrelets elsewhere in outer Kachemak Bay during these fall surveys.

Juvenile Distribution

Marble murrelet juveniles were found along the south outer bay and the south inner bay in roughly equal proportions, with few juveniles in the central region of the south shore or in the north outer shore (Fig. 21). Kittlitz's murrelet juveniles were found primarily in the same area as Kittlitz's adults, between Glacier Spit and Aurora Lagoon, and generally < 1.5 km from shore (Fig. 22). However, for 2004-2007 combined, 25 % of observed Kittlitz's juveniles were recorded farther west along the south side, from the Eldredge Passage area to the mouth of Seldovia Bay, and one near the outer north shore.

During our inland search of Grewingk Glacier Lake, we did not observe any Kittlitz's murrelets. We did however observe approximately 2,000 – 3,000 glaucous-winged gulls on rocky islands in the lake. There were also a few dispersed breeding pairs of arctic terns (*Sterna paradisaea*) nesting along the lake edges.

Foraging Observations

Murrelets that were recorded as actively foraging during our surveys were concentrated in the south inner bay within ~ 2 km from shore (Fig 24). Marbled murrelets were also foraging near shore along the south outer shoreline and islands of Eldredge Passage, and in scattered locations in the north outer bay and bay mouth (Fig. 23). Actively foraging Kittlitz's murrelets were almost entirely in the south inner bay, again within ~2 km of shore (Fig. 24). Marbled murrelets sitting on the water's surface holding fish (indicative of chick-feeding) were observed in the south inner bay between Glacier Spit and Bear Cove, in Halibut Cove, and the Eldredge Passage area, with roughly equal numbers of birds in the inner and outer bay (Fig. 25). All but two Kittlitz's murrelets that were observed holding fish were in the south inner bay, between Glacier Spit and Aurora Lagoon (Fig. 25).

Of the 56 fish held by marbled murrelets, 9 fish were identified, including 8 sand lance (*Ammodytes hexapterous*) and 1 juvenile Pacific herring (*Clupea pallasii*). The fish ranged from 2 to 7 eye-to-bill tip length (mean = 23 mm; Kuletz 2005), indicating that fish were 46 – 161 mm in length. Of the 28 fish held by Kittlitz's murrelets, 6 were identified and all were sand lance, ranging in size from 4 to 7 eye-to-bill tip length (27 mm; Kuletz unpublished data), indicating fish lengths of roughly 108 – 189 mm.

Murrelet Distribution and Bathymetry

The water depths within our July transect (using a 200 m^2 buffer for the transect) were similar to water depths for the entire bay, based on GIS summaries of depth classes (Fig. 26), indicating that the transects were representative of available water depth classes within the bay. During July surveys, both murrelet species showed differences among years in their distribution relative to water depths, although these were not statistically different from expected use. Marbled murrelets were primarily in water < 40 m deep in 2005 and 2006, but were equally distributed in 41-80 m depths in 2007, and showed some use of waters 81-120 m deep in 2007 (Fig. 27). Kittlitz's murrelets were in water 0 – 80 m deep, although in 2006 the majority (78%) were in waters < 40 m (Fig. 26). For the three years combined, marbled murrelets were found primarily in water depths of < 40 m (59%), followed by 41-80 m (33 %), and the remaining birds in waters > 80 m deep (mainly in 2007). Kittlitz's murrelets

were found in roughly equal proportions in water depths of < 40 m (49 %), 41-80 m (51 %), and < 1 % in deeper water.

Water column characteristics

Inner vs. outer bay in July 2006. -- In 2006 the water column in the outer bay (line 12; Fig. 6), was well mixed whereas the inner bay (lines 3 and 2; Fig. 6) was highly stratified (Fig. 27). Line 12 had a weak frontal signal in the upper portion of the water column along the north shore (Fig. 27, top row), with slightly warmer, fresher water on the north side and warmer temperatures to depths of about 25 m, over the shelf. In the inner bay off of Glacier Spit (line 3), a warm, fresh surface layer of 5-10 m depth was evident throughout, and water < 8^0C was 25 – 50 m deep (Fig. 28, middle row). Turbidity, however, was very different along the north-south gradient in the inner bay. On the north side, water was turbid to the bottom (20 m) near shore, and to a depth of at least 10 m towards mid-bay. On the south shore, the surface layer of turbid water was < 2 m deep, with very clear water below 5 m. This clear water extended to the bottom near the south shore and to mid-bay before meeting the tongue of turbid water from the north. Off of Aurora Lagoon (line 2), the pattern was similar to line 3, except that colder water < 8^0C was higher in the water column, at 10 – 20 m depth. In addition, the turbidity along the north shore was more complicated, with thin, multiple layers of turbid and clear water (Fig. 27, bottom row).

Inner bay in July 2007. -- In July 2007 we increased the number of CTD stations along lines 3 and 2 in the inner bay to improve resolution. Although there were minor differences from 2006, the basic patterns were the same, with highly stratified waters and a shallow (< 5 m depth) thermocline (Fig. 28). In 2007, however, the cold water extended from the bottom to higher in the water column along both lines, and water < 7^0C extended up to 20 m from the surface along the south side (Fig. 28, left column). Off of Glacier Spit (line 3), a thin turbid layer went to 5 m, with clearer water below extending to the sea floor. On the north side of line 3, in addition to surface turbidity, there were at least two layers of turbid water extending to mid-bay. Off of Aurora Lagoon (line 2), the south shore had moderately clear water to about 15 m depth, and at least three discreet layers of turbid water, with the bottom layer of turbid water starting at about 35 m on the south side and 25 m on the north side (Fig. 28, right column).

Inter-annual comparison in the outer bay. -- The Barabara line is 4 km east of line 12 in the outer bay, and crosses the north outer bay 'hot spot' where murrelets were occasionally abundant. This area had well defined fronts in July of 2005, 2006, and 2007, particularly on the north side. The north side front of turbid, fresh, warm water flows over a relatively shallow underwater shelf that is approximately 30-40 m deep (evident as dark gray bottom topography in the water profile). The front extended from the surface to approximately 15 m depth, but it varied among years and was typically < 10 m at its deepest (Fig. 29). Water temperature along the Barabara line shows weak stratification, with warmer water in the upper 10 - 20 m in 2005 and 2006, but only on the north side in 2007. In 2005 and 2006, waters < 8^0C were generally > 60 m deep, but in 2007 a band of cold water extended to the shelf edge on the north side (Fig. 29, left column). Also in 2007 a large pool of water < 7^0C was evident in the deepest trough. Salinity was generally well mixed, but fresh water signals were evident over the north side shelf in 2005 and 2006, and less so in 2007 (Fig. 29, center column). A much smaller front is evident in the fresh water signal near the south shore in 2005 and 2006. Turbidity was only high along the north shore front extending over the shelf, with clear water starting at approximately 5 - 10 m depth (Fig. 29, right column).

The 2005 and 2006 sampling of the Barabara line completed by S. Pegau included a measurement of fluorescence as an indicator of primary productivity. His results show how the strong frontal signals along the north shore, evident from temperature, salinity and turbidity, were associated with high fluorescence (Fig. 30). In 2005 the zone of higher productivity extended from the north shore to mid-bay and to a depth of 10 m, and there was a weaker signal of productivity next to the south shore at 10 – 20 m depth (Fig. 30A). In 2006, the zone of high productivity was concentrated over the shelf and slope break (roughly between latitude 59.61 N to 59.56 N), at a depth of 5 – 20 m (Fig. 30B).

Sea surface measurements. -- The measurements that we took at the water surface prior to each transect show the general increase in sea surface temperatures (SST) from April to August (Table x). In August (when all years were surveyed), average SST varied significantly among years (Kruskal-Wallis chi-square = 83.10, df = 3, $P < 0.005$), with 2004 and 2006 having lower SST than 2005 and 2007 (Table 8). Sechi disk measurements, a visual index of turbidity, suggested that surface waters were more turbid in 2007 than previous years, but the difference wasn't significant (Kruskal-Wallis chi-square = 6.59, df =

3, $P = 0.086$). There was no difference in sea surface salinity (SSS) among years (Kruskal-Wallis chi-square = 1.98, df = 3, $P = 0.58$).

DISCUSSION

Murrelet Abundance

We provide population estimates of Kittlitz's and marbled murrelets (Appendix C), as well as other seabirds (Appendix E), for all of Kachemak Bay in June and July. Based on the three-year average of the July point estimates, Kachemak Bay currently supports approximately 10,600 marbled murrelets and 1,900 Kittlitz's murrelets. The most recent summary of the total estimated Kittlitz's population in Alaska (USFWS 2007) is 15,983 (range 7,760 – 26,962). Our results therefore indicate that the Kachemak population represents approximately 12 % of the known Kittlitz's population. The much larger population of marbled murrelets in Kachemak Bay may represent only 1 % of the estimated Alaska population, if estimates from the early 1990s are considered stable (Piatt et al. 2007). However, if typical rates of decline are applied to large areas that lack current estimates, such as Lower Cook Inlet and Southeast Alaska, the Alaska population may only be ~ 272,000 birds (Piatt et al. 2007), and the Kachemak Bay population would then represent 4 % of that total. Thus, although marbled murrelets are the numerically dominate species in Kachemak Bay, the population of Kittlitz's murrelets contributes more to the species' metapopulation. Based on our results for other species in Kachemak Bay (Appendix C-2), *Brachyramphus* murrelets comprised 15 – 22 % of all birds during July, and thus they are an important component of the local avifauna as well.

Interannual variability was high, and a confounding factor was the apparent influx of murrelets in 2006, especially Kittlitz's murrelets, into the north outer bay. It was beyond the scope of this study to determine the frequency of this occurrence on an intra- or inter-annual scale, but the region warrants further study to determine its importance to the Kittlitz's murrelet population. Because numbers of Kittlitz's murrelets remained roughly the same in the inner bay, it is likely that the high numbers of Kittlitz's murrelets in the north outer bay in 2006 were part of a fluid Lower Cook Inlet population. In 1993, the FWS survey of Lower

Cook Inlet resulted in an estimate of > 58,000 *Brachyramphus* murrelets (Agler et al. 1998), and found large numbers, including Kittlitz's murrelets, occupying waters just outside of north Kachemak Bay and south of Anchor Point (Fig. 31; modified from data used in Agler et al. 1998). More recently, while conducting hydrographic surveys, S. Pegau (pers. comm.) reported frequent observations of murrelets during multiple crossings of this area over several years. If this larger area has generally high foraging activity, birds could be moving into and out this region of Kachemak Bay depending on tidal and seasonal influences on prey. It is apparent that a true measure of this region's trends in *Brachyramphus* murrelet population will require a resurvey of the larger Lower Cook Inlet.

The population size of Kittlitz's murrelets occupying the inner bay is not large, but the density of birds in that hot spot is high compared to areas such as Kenai Fjords, Lower Cook Inlet, and Prince William Sound. Between 2005 and 2007, average Kittlitz's murrelet density for the entire bay was 2.38 ± SD 1.32 birds • km^{-2}, and for the inner bay specifically, density was 5.38 ± SD 1.75 birds • km^{-2} (Table 3). The inner bay would thus be second only to Icy Bay, based on results from surveys in Southeast Alaska in 2002 – 2004 (Kissling et al. 2007b).

Murrelet Population Trends

Monitoring population trends of marbled and Kittlitz's murrelets is complicated by variable rates of species identification, in particular the low proportion of birds identified in historic surveys (Kuletz et al. 2005). At least since the 1970s, marbled murrelets have always been more abundant than Kittlitz's murrelets in Kachemak Bay. The apparent increase in marbled murrelets is usually concurrent with declines in unidentified murrelets, and simply reflect improved identification in recent years. For this reason, the most meaningful data sets to examine are the trends in Kittlitz's murrelets and trends in total *Brachyramphus* murrelets.

The June surveys did not reveal a decline in Kittlitz's murrelets since 1993, despite the absence of Kittlitz's in 2005. Marbled murrelets appeared to increase since 1993, but when examined with the trend for total murrelets, there was no change between 1993 and the 2005 - 2006 surveys. The 2006 spike in murrelet numbers for both species makes it difficult to analyze trends with just three years of data for June.

The trends in murrelet densities during August surveys showed significant differences from some historic transect sets. Between decades, Kittlitz's murrelets declined significantly in the inner bay and in the entire bay, and individual Transect Sets (Table 4) indicated a decline in the inner bay for Kittlitz's murrelets of between - 4 to -18 % per annum. This is consistent with declines noted in other populations in the Gulf of Alaska (USFWS 2007).

Compared to historic surveys, densities for total murrelets in recent surveys were slightly lower for the entire bay, and identical in the inner bay. Densities for total murrelets increased in the outer bay, and this appears to be due to an increase in marbled murrelets, since Kittlitz's densities declined between decades (Table 5). At a finer scale, the transect sets indicated that the increase in marbled murrelets in the outer bay was primarily along the south outer shore, since that area also showed a concurrent increase in unidentified murrelets. The results suggest a 9 % per annum increase in marbled murrelets along this stretch of shoreline (Table 5). While this is a relatively small area, it is one of only two data sets that show an increase in marbled murrelets, the other being a temporary increase in the Kenai Fjords between the 1980s and 2002 (Piatt et al. 2007). Because of a possible shift in distribution within the bay and likely movement of birds near the bay's confluence with Lower Cook Inlet, a resurvey of the Lower Cook Inlet region would be required to determine if there has been a positive population trend.

We conclude that the decline in Kittlitz's murrelets is real, and in fact is likely conservative, because low species identification rates in historic surveys would have reduced density estimates for identified Kittlitz's in early years. The rate of decline in the inner bay, where Kittlitz's murrelets were always present and aggregated, is an indication of a compromised population, and is comparable to declines in other summer breeding areas within its range. Since the 1980s or early 1990s Kittlitz's have declined dramatically in Prince William Sound at -18% per annum (Kuletz et al. 2005), in Kenai Fjords at – 8.7 % per annum (Van Pelt and Piatt 2003), and Glacier Bay at – 8.9 % per annum (Robards et al. 2003). Our results lend support to the argument for listing of Kittlitz's murrelets as a threatened species.

The trends in marbled murrelets are more problematic, but suggest that the overall population may be stable, with a possible shift in distribution to the outer bay. Murrelets did, however, decline in Eldredge Passage, which is in the central part of the south shore and in

terms of oceanographic characteristics, borders the inner bay (Speckman 2004). Despite apparent increases in the outer bay since the 1988 – 1999 period, the annual declines in July population estimates for marbled murrelets between 2005 and 2007 suggest that caution is warranted before concluding that the population is stable.

Potential Influences on Murrelet Populations

One of the primary factors considered to be a potential cause for the range-wide decline in Kittlitz's murrelets is the alteration of glacial-associated habitats due to climate change (USFWS 2007). The stability or recession of tidewater glaciers has been linked to murrelet habitat use (Day et al. 2000, Kissling et al. 2007a) and to population declines (Kuletz et al. 2003a). Land-based glaciers such as occur on the south side of Kachemak Bay can also respond to short-term climate change (Hall et al. 2005). The water column structure in the Kittlitz's murrelet hot spot was relatively restricted spatially, and could be subject to changes in flow and sedimentation caused by further retreat of the associated land-based glaciers. Hall et al (2005) concluded that since at least 1973, the Grewingk-Yalik glacier complex that feeds into inner Kachemak Bay has been more stable than the glaciers from the Harding Icefield that feed into Kenai Fjords. This local stability may have resulted in a refugium for Kittlitz's murrelets. The importance of the glacial outflow near Glacier Spit and Aurora Lagoon is apparent when our survey results are overlaid with satellite imagery of the bay (Fig. 32). Kittlitz's murrelets are clearly associated with the plume of glacial silt, and densities are particularly high on the western edge of the plume near Glacier Spit.

Marbled murrelets also foraged extensively in the glacial outflow of the south inner bay, and thus would also be affected by changes to this habitat. Sand lance was a primary prey in this area of the bay, and this important forage fish depends on fine gravel and sandy substrates (Robards et al. 1999), which could be altered with changes in sedimentation and sill formation. Additionally, marbled murrelets have likely been affected by drastic alteration of the upland habitat that has resulted in loss of nesting habitat. Increasingly warmer springs have led to outbreaks of spruce bark beetles in southcentral Alaska (Berg et al. 2004). Spruce bark beetles have removed forests from much of the Kenai Peninsula (Fig. 33), and aerial surveys show that deforestation became evident in inner Kachemak Bay in 1992, with peak infestation rates in the mid 1990s (Fig. 34). Outer Kachemak Bay has been less

affected and this may be one reason for the apparent shift by marbled murrelets into the outer bay. There has not been a comprehensive study of upland nesting habitat using dawn surveys to gauge this potential impact. It may be possible to conduct a comparative study between outer and inner uplands using radar to detect inland flights.

Other potential factors affecting murrelets include gillnet mortality, increased boat traffic, and changes in prey (Day et al. 1999, Nelson 1997, Piatt and Anderson 1996). Oil spills are also a risk (King and Sanger 1979, Van Vliet and McAllister 1994), although the murrelet populations in Kachemak did not show evidence of direct impact from the 1989 *Exxon Valdez* spill (Kuletz 1996). There are salmon gillnet set net sites in Kachemak Bay, primarily along the outer south side. A two-year study of gillnet mortality in the set net and drift gillnet commercial salmon fishery of Cook Inlet estimated about 37 murrelets were taken annually. However, sampling effort was too low to accurately gauge seabird bycatch for this fishery (Manly 2006). In the Kodiak Island set gillnet salmon fishery, Manly et al. (2007) estimated that between 56 (2002) and 143 (2005) murrelets per annum were taken incidentally, and this included 17 Kittlitz's' murrelets. Wherever gillnets and murrelets overlap, gillnet mortality is known to occur (Piatt et al. 2007). However, even if these numbers are representative of potential bycatch of murrelets in Kachemak Bay, they are small relative to the population, and at least currently, few murrelets occupy the nearshore areas where set gillnets were deployed during our surveys.

Compared to the locations of other populations of Kittlitz's, Kachemak Bay has relatively high boat activity, although most of the traffic during our surveys was from recreational or fishing vessels < 45 ft. However, even small boats can disturb murrelets (Speckman et al. 2004), and boat traffic was high throughout nearshore areas, particularly along the southern shore and including the inner bay area < 2 km from the southern shore, and throughout the Eldredge Passage area (Appendix F). Disturbance in forage areas by large vessels can be energetically expensive for murrelets during the breeding season (Agness 2006). We did not analyze the relationship between boat traffic and murrelet density, but this dataset would be one way to examine potential impacts from boat traffic.

Seasonal Patterns of Abundance and Chronology

We observed newly fledged marbled murrelets at sea on the first August surveys of 2005 and 2007, indicating that we did not capture the initiation of fledging for marbled murrelets those years. The patterns of juvenile abundance suggest that marbled murrelet chronology in Kachemak begins earlier and extends over a longer period than does Kittlitz's murrelet chronology. The increase in marbled murrelet juveniles late in August may also indicate a longer residency in the bay, whereas Kittlitz's murrelet juveniles appear to leave the area by late August. This remains speculative, however, due to the low frequency of encounters for Kittlitz's juveniles. We also found it harder to distinguish juvenile from adult Kittlitz's, especially after mid-August, when many of the adults appeared to be molting. Furthermore, the plumage sequence between newly fledged juveniles and older juveniles has not been described, and we observed birds that appeared to be juveniles that were in basic black-and-white plumage as opposed to the dark grey and speckled plumage of newly fledged juveniles (based on videos at nest sites [Van Pelt, unpubl. data] and photo documentation from a variety of contributors).

One of the goals of this project was to determine if Kittlitz's were reproducing, because Day and Nigro (2004) suggested that Kittlitz's murrelets in Prince William Sound (PWS) were not successfully raising chicks. It is apparent that a closer examination of plumage characteristics of juvenile Kittlitz's murrelets is needed so that accurate age class determination can be made. Our experiences in Kachemak Bay and in PWS suggest that juvenile Kittlitz's murrelets could easily be overlooked if they are among adults. Because we had a core crew of people experienced in murrelet identification during the four years of this study, we are confident in the identifications that we made. The information obtained in Kachemak Bay in 2004-2007 constitutes the most complete record available of juvenile Kittlitz's murrelet distribution and density.

Productivity

The low encounter rate with juveniles of both murrelet species makes it difficult to obtain statistical power in detecting changes in murrelet productivity with at-sea surveys, although power can be moderately high in areas with high murrelet densities (Kuletz 2005). At-sea surveys can, however, quickly indicate areas that are important to juvenile murrelets

and they provide a relative index of local productivity (Kuletz 2005). Our data suggest that both murrelets did poorly in 2007, a year that also had the lowest densities of adult murrelets. For Kittlitz's murrelets, there was some evidence of alternating years of good (2004, 2006) and poor (2005, 2007) productivity. Marbled murrelet productivity showed a similar, but less dramatic pattern. For marbled murrelets in particular, however, the 2007 August surveys may have missed the peak juvenile densities, since we could not survey past mid August that year. For Kittlitz's murrelets, juvenile:adult ratios were extremely low in 2006 and relatively high in 2007 (Fig. 14), reflecting high numbers of adult birds present in 2006 and low numbers of adults in 2007. Juvenile densities of both species showed a negative relationship with SST between 2004 and 2007 (Fig. 35), but more years will be needed to determine if SST is a good predictor of murrelet productivity, and to explore the mechanisms involved.

Compared to intensive surveys for juveniles in Kachemak Bay in 1996 (Kuletz and Piatt 1999), marbled murrelet juvenile densities were lower overall in 2004-2007. The mean marbled murrelet juvenile density for 10 survey days between 7 – 24 August 1996 was 1.12 $\pm$ 1.64 birds $\cdot$ km^{-2}, whereas the mean for 2004-2007 was 0.56 $\pm$ 0.22 birds $\cdot$ km^{-2}. However, in 1996 there were two very high juvenile counts in mid and late August which accounted for most of the juvenile observations (Kuletz and Piatt 1999). There also appears to have been a shift in distribution of juveniles. In 1996, 96 % of marbled murrelet juveniles were observed along the south outer shore, primarily between Barabara Point and Seldovia Bay, and Kuletz and Piatt (1999) suggested this was a murrelet 'nursery' area. In contrast, only about half of the juveniles we recorded in 2004 – 2007 were in the nursery area. Although we found juvenile marbled murrelets in the outer bay more than in the inner bay (Table 6), they were dispersed throughout the southern side of the bay (Fig. 21).

In 1996, Kuletz and Piatt (1999) noted that the murrelet nursery area had the only large *Nereocyctis leutkeana* kelp beds, and this appeared to be a defining characteristic. Indeed, Schoch and Chenelot (2004) documented that in Kachemak Bay, *Nereocystis* beds are found only in the outer basin, and they concluded they were not in the inner bay because of the low salinity, high turbidity, and low nutrient levels in the water column of the inner basin.

Aerial surveys documented significant declines in the size and distribution of *Nereocystis* beds in Kachemak Bay (Schoch 2001). The kelp beds were found in the same locations over three years of their study (2000 – 2002), but decreased in size significantly

(Schoch and Chenelot 2004). Kelp forests support local marine food webs (Lalli and Parsons 1993), and have been recognized as habitats preferred by juvenile murrelets throughout their range (Piatt et al. 2007). Anecdotally, Schoch and Chenelot (2004) report local knowledge of historically more extensive kelp beds along the south outer shore. If the *Nereocystis* beds have been declining over the last two decades and are continuing to decline, it could potentially affect the survival of juvenile murrelets in the bay. Adult foraging could also be affected, since Schoch and Chenelot (2004) also found declines in the size of kelp beds along the north outer shore, in the shallow shelf south of Anchor Point to Bluff Point where murrelets occasionally aggregated.

Concurrent with evidence for changes in the marine habitat, there is circumstantial evidence that the food web of Kachemak Bay in general has experienced perturbations, including human-induced changes from fishing and alteration of nearshore habitats that result in sedimentation and pollution (Schoch and Chenelot 2004). Fisheries that have been closed due to population crashes in the past decades include Pacific herring (*Clupea pallasii*) and shrimp (*Pandalus* spp.), and murrelets feed on juveniles of these species (Sanger 1987, Piatt et al. 2007). Sand lance are also an important forage fish for seabirds in Kachemak Bay (Abookire et al. 2000, Litzow et al. 2004, Speckman et al. 2005), and we found both murrelet species feeding on adult sand lance. In July 2006, we noticed continuous feeding activity by a variety of seabirds along the north outer shoreline, and from the beach it was possible to pick up large adult sand lance that were swarming in the shallows. Off shore of this area is where the influx of murrelets occurred that year. The historic abundance of sand lance in Kachemak Bay is unknown, but it was critical to some breeding seabirds in the 1990s (Litzow et al. 2000, 2004). It was evident that sand lance were consistently available to seabirds in the area from Glacier Spit and Aurora Lagoon, suggesting this is an important area to monitor for changes in the food web.

Other forage species for murrelets in Kachemak Bay include capelin (*Mallotus villosus*), mysids and euphausiids (Sanger 1987). Euphausiids are an important prey for Kittlitz's murrelets (Day et al. 1999), but we could not determine where or how frequently they were used by Kittlitz's murrelets by making visual observations. To understand the biology of Kittlitz's murrelets in Kachemak Bay it will be necessary to know more about the abundance and distribution of euphausiids in the bay.

Although we did not find evidence of Kittlitz's juveniles using the glacial lake, a more intensive effort, or radio tagging of a juvenile prior to fledging, is recommended to determine if this is a post-fledging habitat. Of note were the high numbers of glaucous-winged gulls at the lake, which are believed to be the main predators of Kittlitz's murrelet chicks on Attu Island (Kaler et al. *in press*). In addition to high numbers of gulls, the bald eagle population of Kachemak Bay may have increased since 1993 (Appendix E-1), and eagles take both murrelet species on the water (Piatt et al. 2007). Human activity that enhances the populations of these avian predators could have adverse affects on both marbled and Kittlitz's murrelets via predation on eggs, chicks, and adults.

Distribution and habitat use

The abundance of sand lance and other forage fish in Cook Inlet and Kachemak Bay vary considerably with tidal phase, water column structure, and season (Robards et al. 1999, Abookire et al. 2000, Speckman et al. 2005). The CTD casts found temporal differences in depth and magnitude of the halocline and thermocline and associated fronts, but these also depend on tidal phase (Okkonen et al. 2007). The general pattern of water characteristics, however, remained consistent. The distribution of marbled murrelets indicates that they use a variety of marine habitats within the bay, from the highly mixed waters of the outer bay to the highly stratified layers of the inner bay. In contrast, Kittlitz's murrelets were primarily found in the highly stratified waters of the inner bay, where glacial outflow was most intense (Fig. 32). A particular feature of these areas was a layer of clear water typically < 5 m below the surface layer of turbid water. Water depth appears to be a primary limiting factor, as most murrelets occurred in water < 60 m deep (Fig. 26).

The exceptionally high densities of both murrelet species in the north outer bay in July 2006 occurred in an area with strong frontal properties, particularly at a zone of convergence 4 – 5 km offshore, with a strong turbidity front. Within this frontal zone, murrelet densities were highest where the bottom topography forms a relatively shallow shelf, and the deep trench to the south of this shelf is a feature that can focus the general outflow of water from the bay, and thus maintain the frontal zone (S. Pegau, pers. comm.). Additionally, approximately 5 - 10 km from the north shore is the edge of a cyclonic eddy that varies in size with tidal phase (Okkonen et al. 2007, Pegau, unpubl. data), and this area also attracted

high densities of marbled murrelets. Another area of intensified water exchange is Eldredge Passage, which was a marbled murrelet hot spot. The Eldredge Passage area was identified as a marbled murrelet hot spot in the 1970s (Erickson 1977) and in 1993 (Kendall and Agler 1998). Areas of upwelling, tidally induced mixing, and fronts act to concentrate prey species in the upper water column, and are known to attract seabirds, and murrelets in particular (Coyle et al. 1992, Hunt 1995, Hunt et. al. 1999). The decline of murrelets in the Eldredge Passage area may be indicative of changes in the marine habitat that affect prey, but could also be associated with high boat traffic through the passage (see Appendix F).

The location of marine foraging areas relative to nesting habitat may be a limiting factor for both murrelet species. Kachemak Bay offers a variety of both marine and upland habitats within ~ 60 km of each other, which is below the known maximum foraging range of marbled murrelets (Piatt et al. 2007), and possibly for Kittlitz's murrelets as well (M. Kissling, unpubl. data). Nonetheless, a rough GIS measure of the Kachemak Bay foraging spots relative to potential nesting habitats (Table 8) suggested that the south inner bay and Eldredge Passage are the most readily accessible for birds nesting along the south shore. In contrast, the north outer bay (which does not have nesting habitat for either murrelet species) had the greatest distances from most south side watersheds (range 35 – 56 km). Notably, however, the one discovered nest of a Kittlitz's murrelet on Red Mountain (Piatt et al. 1999) was one of the farthest potential nest sites from the inner bay, at 42 km one-way. Indeed, a bird could fly through the mountain passes between the inner bay and the Kenai Fjords with one-way trips of only 10 - 40 km (Table 8), depending on the route. Because people have provided anecdotal reports (to KJK) of murrelets flying through the passes at dawn, it is possible that some of the birds in Kachemak Bay are nesting on the south side of the Kenai Peninsula.

Both murrelet species appear to leave the bay during the night, at least the inner bay and nearshore areas. We were unsuccessful at finding murrelets at night in areas that had high densities during the day. This diel pattern was also observed by KJK during 24 hour land-based watches conducted in 1988. Whether the murrelets move offshore into the outer bay, or farther into Lower Cook Inlet, or even the Kenai Fjords, remains unknown.

Distribution of Other Species

The mapped distributions of marine birds and mammals show that some species or species groups frequent certain areas of the bay, indicative of habitat preferences. For example, pigeon guillemots were most abundant along the south shore (where they have numerous colonies), but were also observed diving over the shallow shelf of the north outer bay (Appendix F). Sea ducks were found primarily along the south shore and near MacDonald Spit in the outer bay, whereas common murres occupied the middle, deepwater portions of the bay. Black-legged kittiwakes were ubiquitous, but showed less use of the turbid north inner bay and of the deep waters of the central outer bay. Harbor seals were most abundant in the inner bay, while the largest groups of sea otters were in the outer bay. A full description of the distributions of other species is beyond the scope of this report, but will be available through the NPPSD and from the authors on request.

Recommendations

Both murrelet species increased in number between June and July surveys, particularly for Kittlitz's murrelets, which were rarely observed during mid-June surveys. The peak in mid-July numbers corresponds to the chick rearing period, when both members of a nesting pair are at sea, and thus would be the best time to obtain maximum population counts. High variance due to clumped distribution was particularly evident for Kittlitz's murrelet, and this problem has been noted in Prince William Sound (Kendall and Agler 1998) and Icy Bay in Southeast Alaska (Kissling et al. 2007b). The annual and seasonal patterns of distribution and abundance of murrelets will assist in development of appropriate protocol for long-term monitoring, as well as identify sensitive marine habitats.

In the Gulf of Alaska, many large populations of Kittlitz's murrelets are associated with tidewater glaciers (Day et al. 1999, Kuletz et al. 2003a, Kissling et al. 2007a,b). The floating brash ice and icebergs make surveying for Kittlitz's difficult. In addition to the logistical constraints and safety issues, the ice can affect detectability of murrelets, prohibit surveys of the same areas among days (due to movement of ice with winds and tides), and alter the surface area to which counts are extrapolated for population estimates (Kissling et al. 2007a). Kachemak Bay, with no floating ice, does not have these disadvantages, and thus population estimates should be more reliable, at least in the inner bay where the population is highly

concentrated and always present from late June to early August. The easternmost area of the inner bay is less than an hour boat ride from the Homer harbor, which makes the area readily accessible in most days of the year. We conducted most of our surveys in the morning hours to avoid the afternoon winds that are typical in Kachemak Bay and can produce seas that reduce murrelet detectability.

Confidence intervals were proportionally higher for Kittlitz's murrelets than for marbled murrelets, due to the former's clumped and limited distribution. The high variance could probably be reduced for Kittlitz's murrelets by increasing survey intensity (number of transects or replicates) within the two 'hot spots'. In particular, monitoring of the south inner bay, within a 4 km band off of Glacier Spit to Bear Cove, would be essential to obtain trends and productivity data on Kittlitz's murrelets. Still, because of the movement of birds in the outer bay, a true measure of this region's trends in *Brachyramphus* murrelet population will require a resurvey of the larger Lower Cook Inlet.

To enable long-term monitoring of murrelets in Kachemak Bay, it will be necessary to maintain trained personnel, since species identification is critical to detecting population changes of a rare species that co-exists with a more abundant species (Kuletz et al. 2005). An examination of plumage characteristics of juvenile Kittlitz's murrelets is also needed so that accurate age class determination can be made.

Because Kittlitz's murrelets have declined in Kachemak, as they have in other areas, the bay's location would be the most convenient for future research into causal factors, or to refine monitoring methods. For marbled murrelets, there is the unique opportunity to track population size and indices of productivity following large-scale loss of breeding habitat due to 'natural' insect infestation. We recommend a comparative study between outer and inner uplands using radar to detect inland flights into infected and uninfected watersheds.

The Kittlitz's murrelet population in particular is a unique aspect of the Kachemak Bay ecosystem, and additionally, they are important to the world population of the species. We recommend a public outreach effort to educate Alaskans and tourists about the ecology of Kittlitz's murrelets and their status relative to human activities and climate change. Conservation efforts could stress the importance of minimizing disturbance on the water and preventing human activities that attract avian predators such as gulls and bald eagles.

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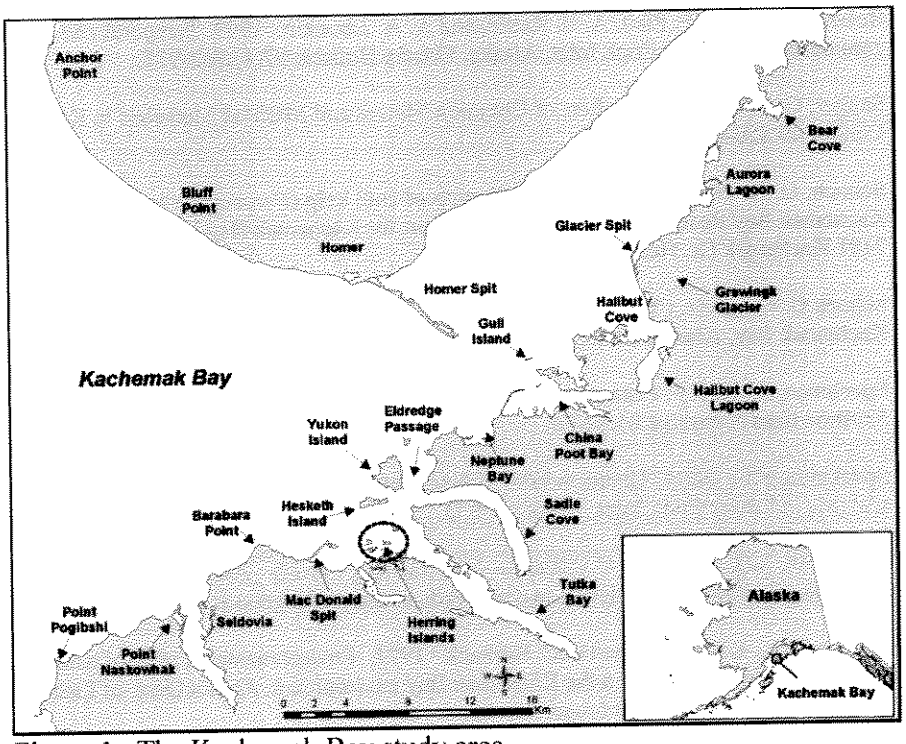


Figure 1. The Kachemak Bay study area.

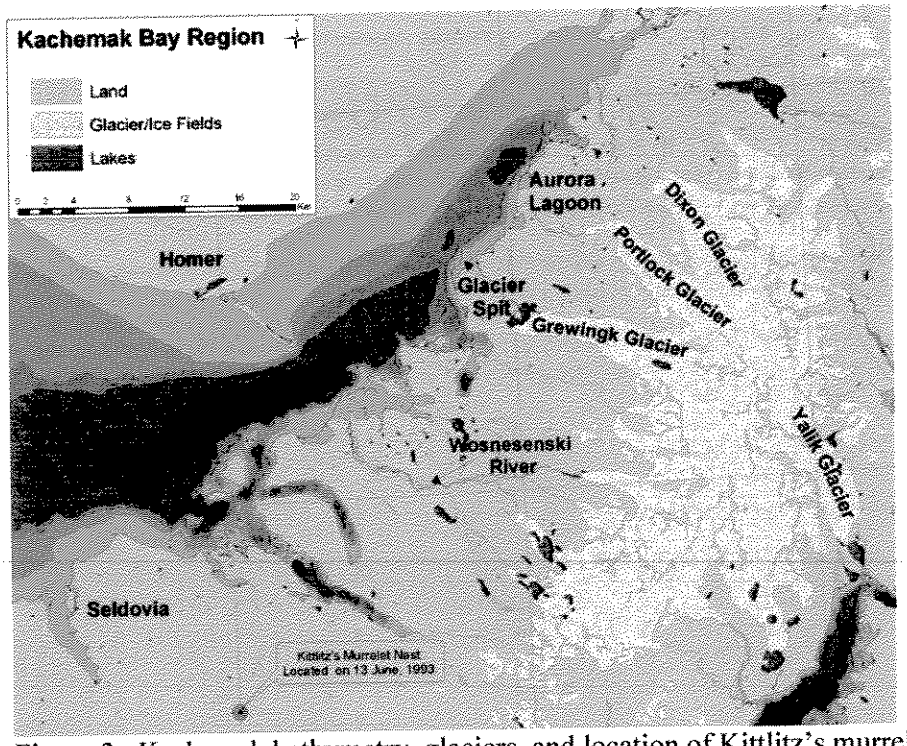


Figure 2. Kachemak bathymetry, glaciers, and location of Kittlitz's murrelet nest discovered in 1993 (green dot).

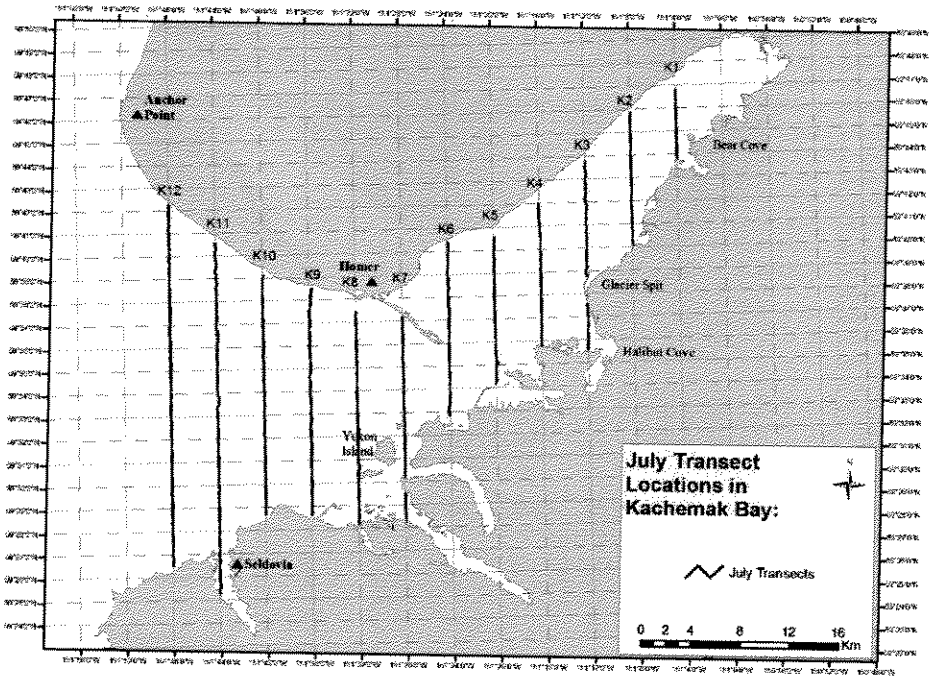


Figure 3. Transects surveyed between 18-25 July of 2005, 2006, and 2007.

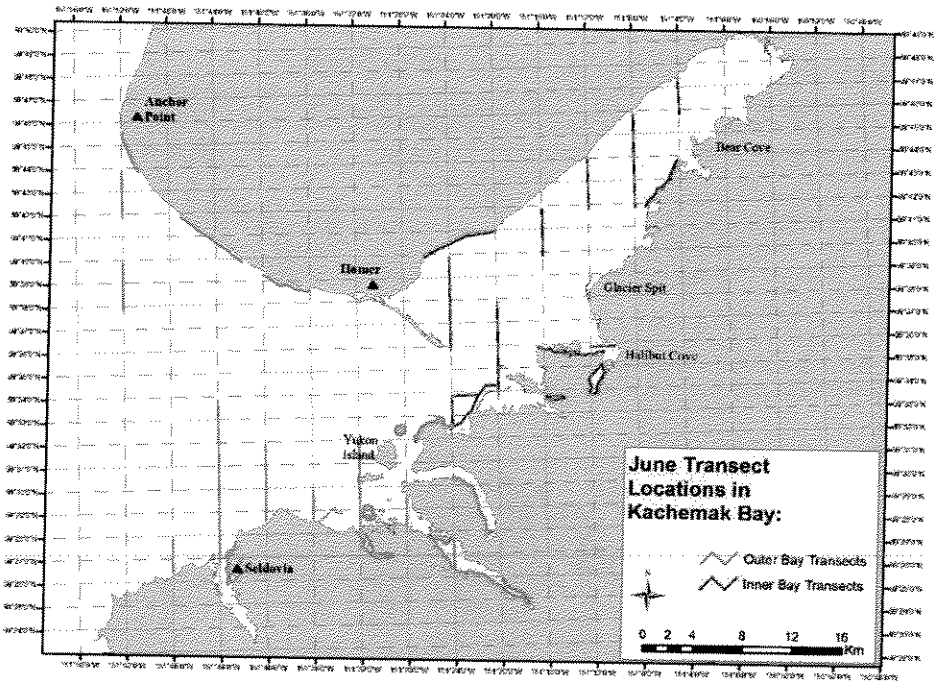


Figure 4. Location of transects surveyed between 16 – 20 June in 2005 and 2006. These transects were originally surveyed in 1993 as part of a USFWS survey of Lower Cook Inlet, and were randomly selected from shoreline and pelagic strata

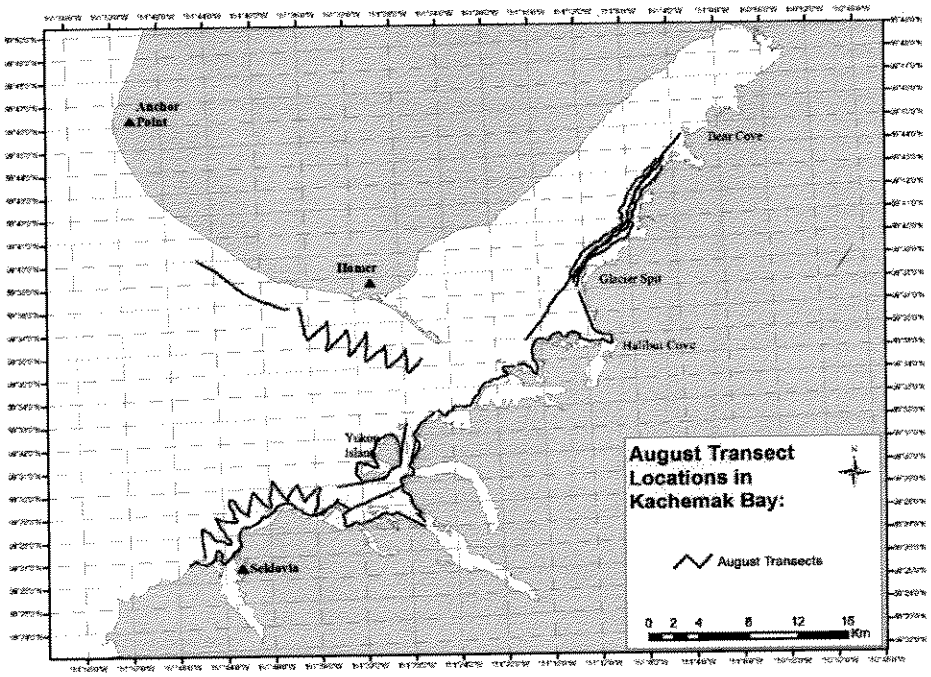


Figure 5A. Historic transects that were surveyed in August of 2004 – 2007. See Appendix A-3 for individual transect reference numbers.

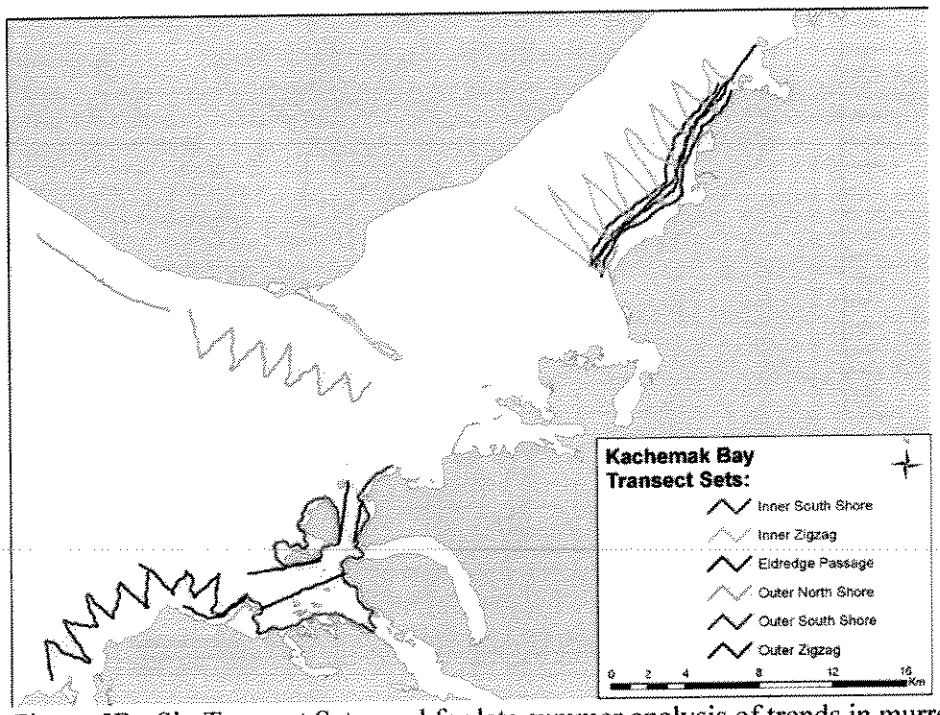


Figure 5B. Six Transect Sets used for late summer analysis of trends in murrelet density. Each set of transects could be surveyed in one day and had historic and recent survey coverage.

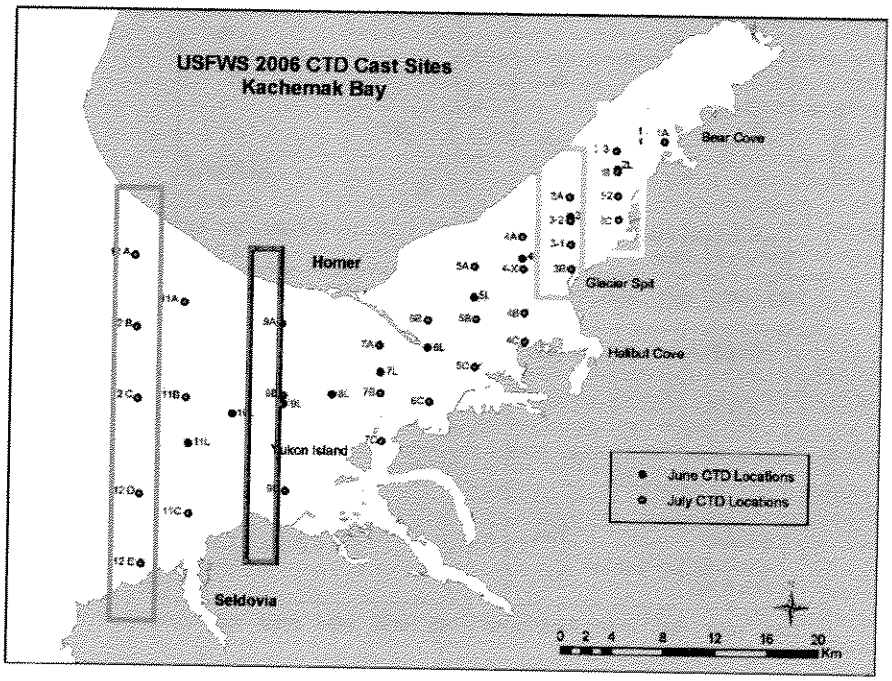


Figure 6. Location of CTD sampling lines used to derive water column profiles. Line 12 (orange box), line 3 (gold box), and line 2 (yellow box) were sampled by the FWS. The Barabara line (red box; 10 stations not shown) was sampled by Dr. Scott Pegau in 2005 and 2006, and by FWS in 2007

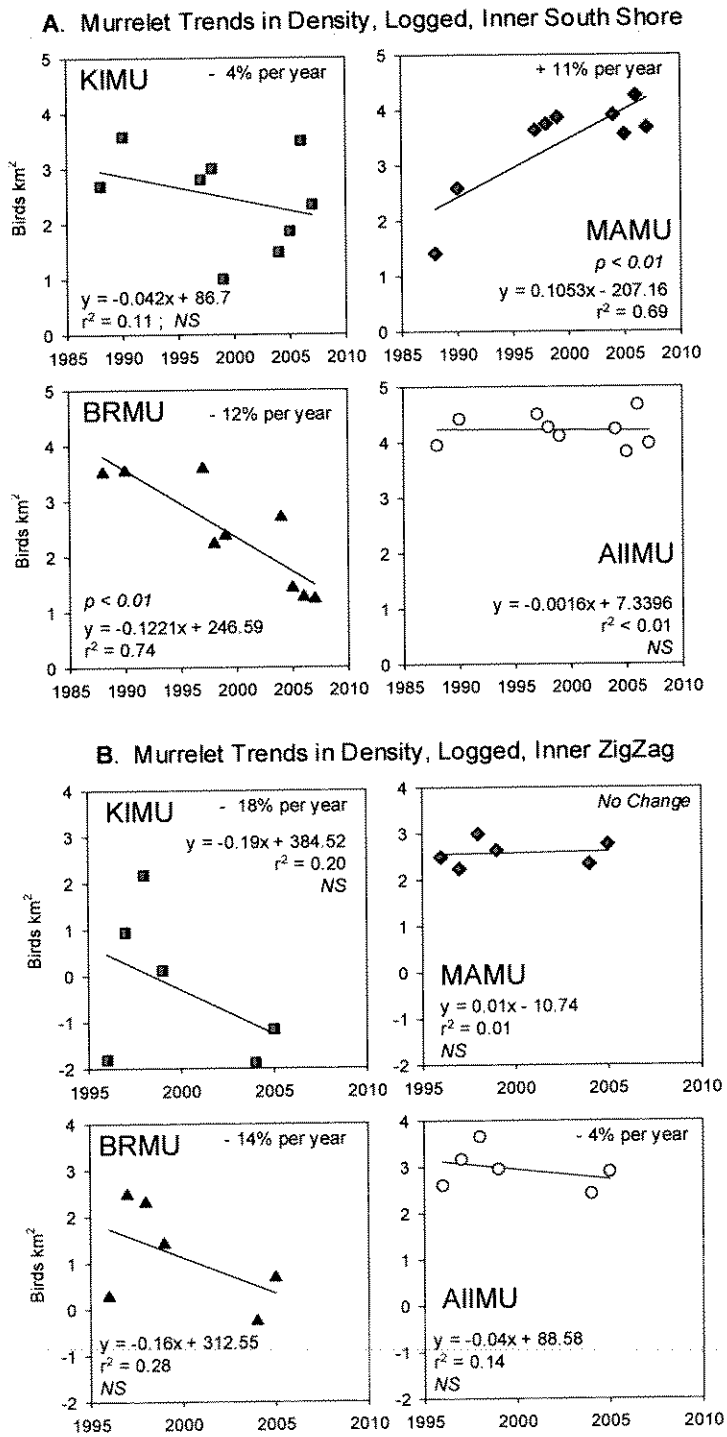
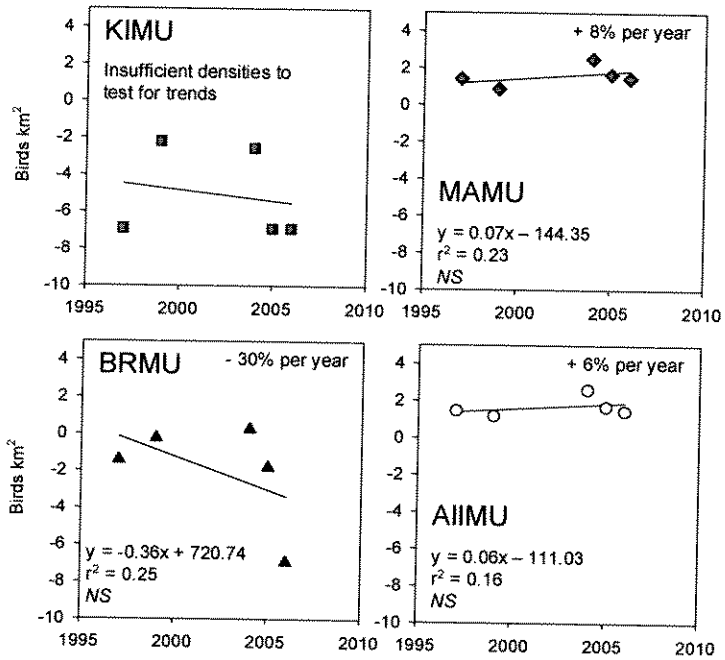
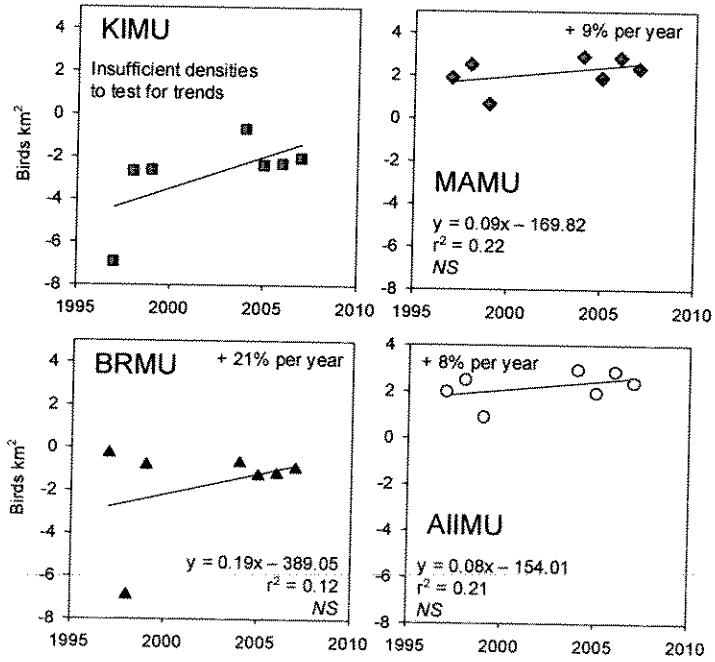


Figure 7 A-F. Trends in murrelet densities (logged), based on late summer surveys in Kachemak Bay, Alaska.

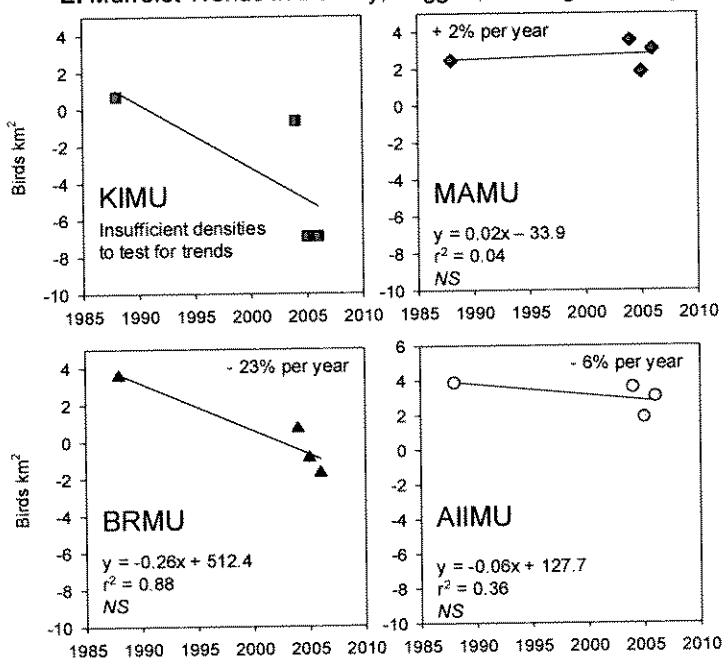
C. Murrelet Trends in Density, Logged, Outer Zigzag



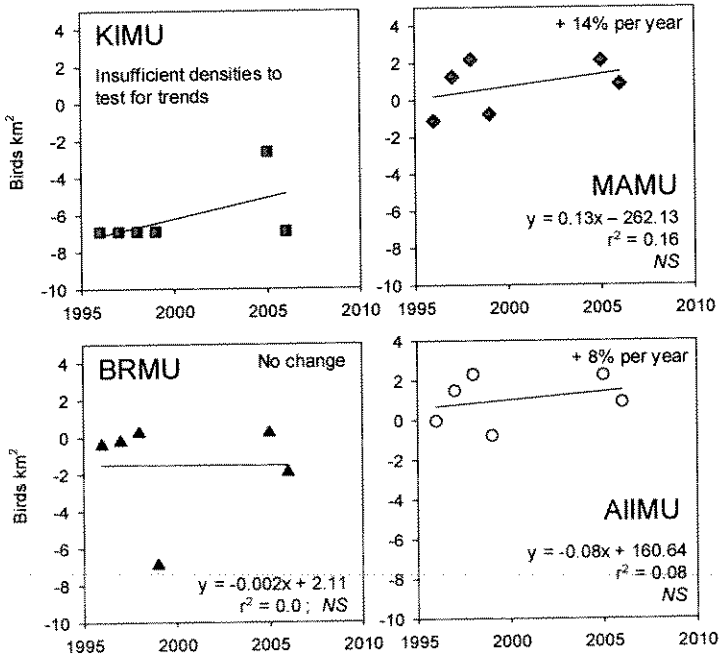
D. Murrelet Trends in Density, Logged, Outer South Shore



E. Murrelet Trends in Density, Logged, Eldredge Passage



F. Murrelet Trends in Density, Logged, Outer North Shore



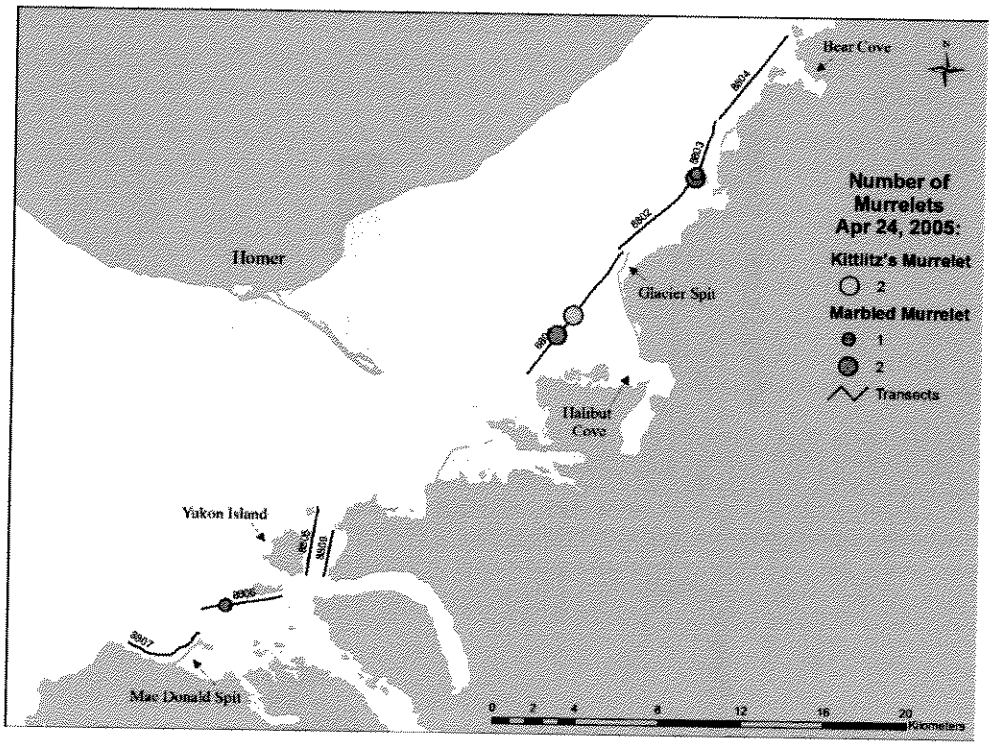


Figure 8. Location of marbled and Kittlitz's observed during a survey of south shore transects on 24 April, 2005 in Kachemak Bay.

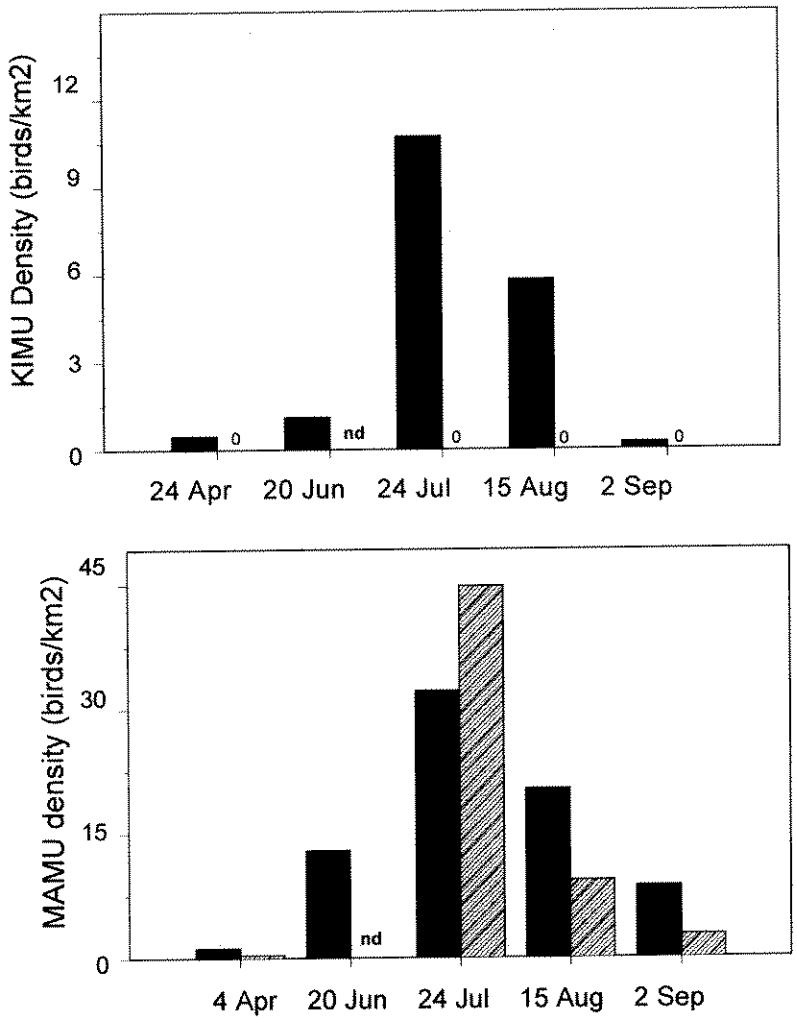


Figure 9. Seasonal patterns of abundance for Kittlitz's murrelets (top) and marble murrelets (bottom) based on at-sea surveys of the same Transect Sets in the inner bay (black bar) and outer bay (striped bar) regions of Kachemak Bay in 2005. No Kittlitz's murrelets were observed during these surveys in the outer bay. The outer bay transects were not surveyed in June. Nd = no data.

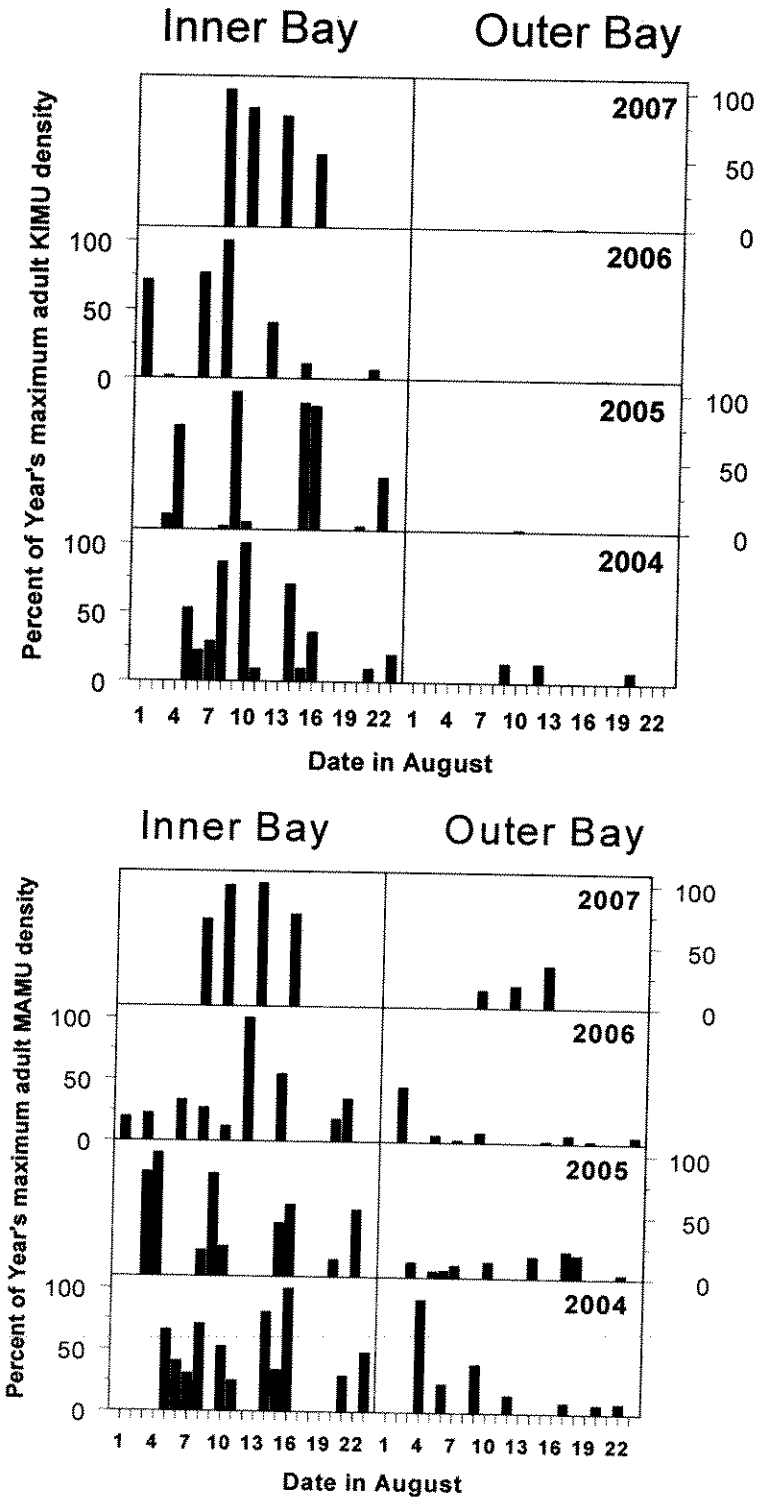


Figure 10. Relative abundance of adult Kittlitz's murrelets (top) and marbled murrelets (bottom) throughout August, 2004-2007

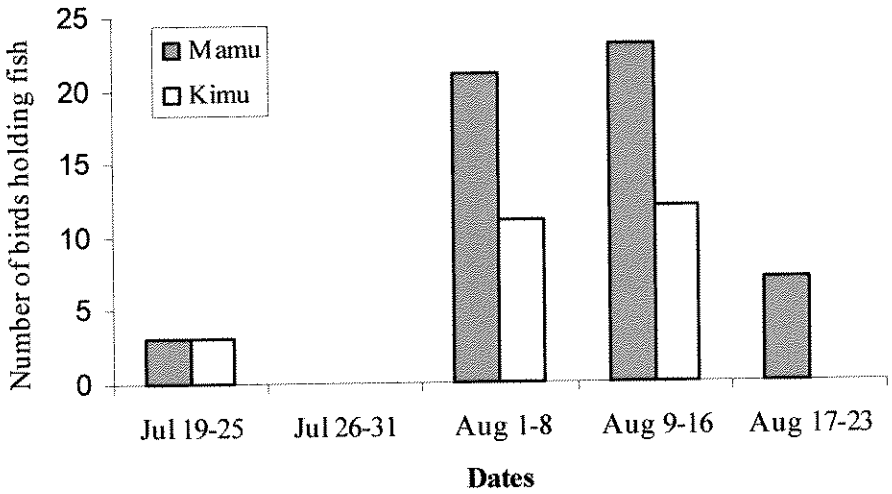


Figure 11. Number of adult murrelets observed holding fish (indicative of chick rearing), by weekly periods, in Kachemak Bay during boat-based surveys in late July through August of 2004 – 2007.

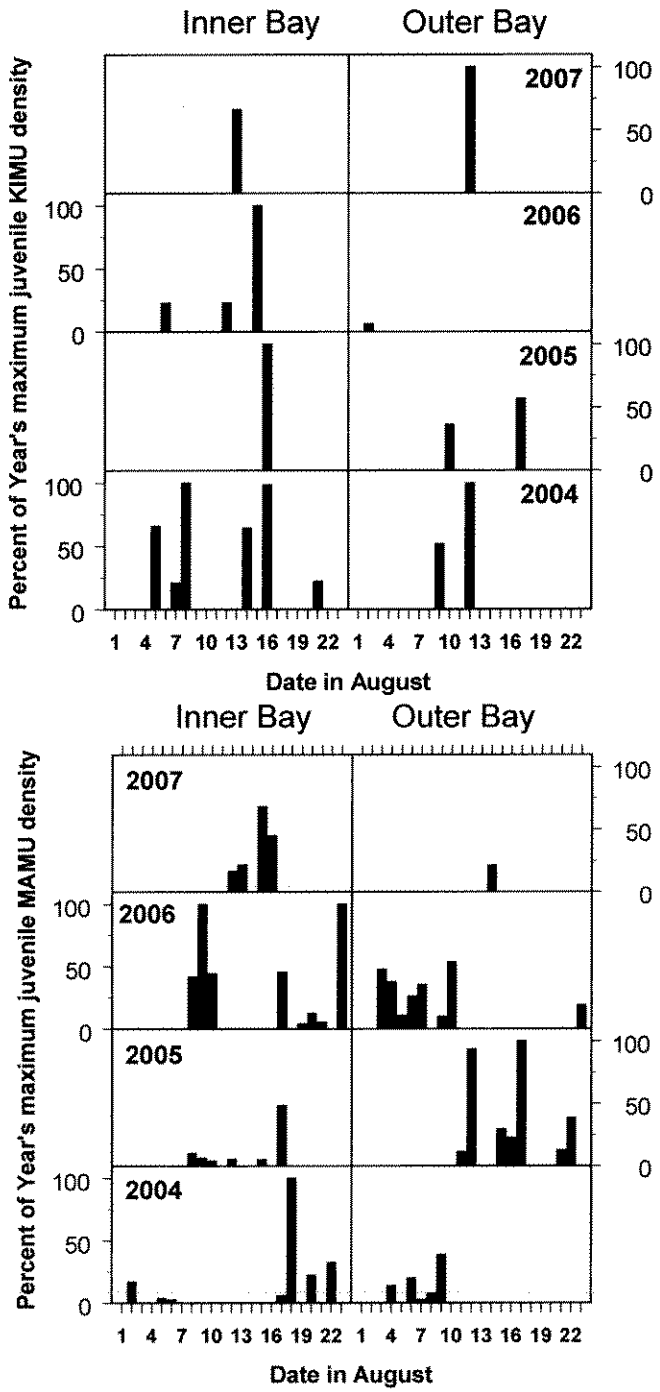


Figure 12. Relative abundance of juvenile Kittlitz's murrelets (top) and juvenile marbled murrelets (bottom) throughout August, 2004-2007.

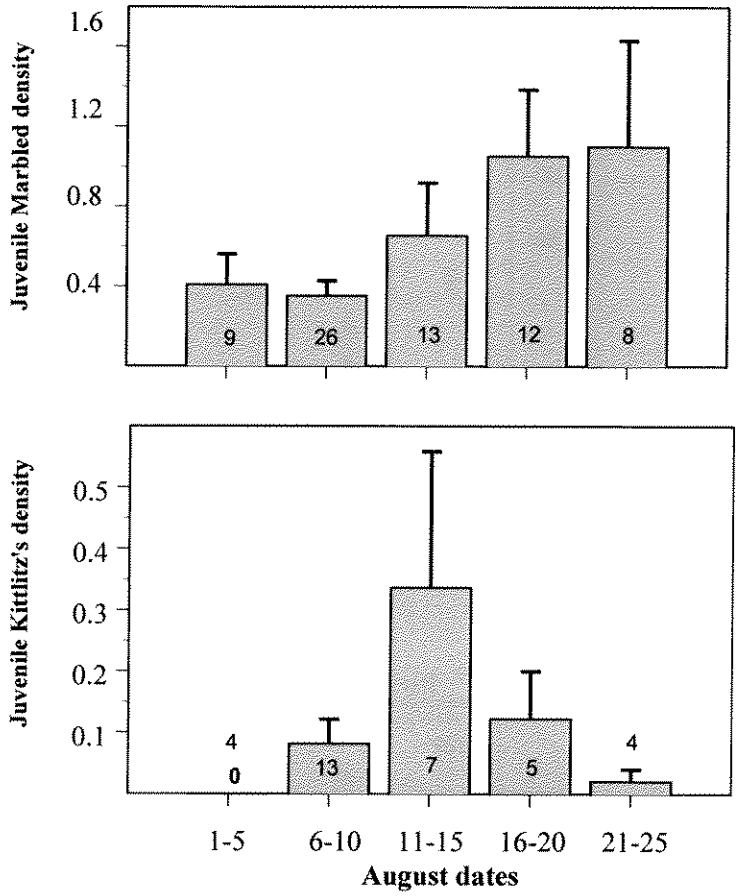


Figure 13. Mean (± SE) density (birds• km^{-2}) of juvenile marbled murrelets (top) and Kittlitz's murrelets (bottom), summarized in 5-day periods in August (except for 21-23), 2004-2007. Juvenile marbled murrelet densities include surveys conducted throughout Kachemak Bay because juveniles were widely distributed. Juvenile Kittlitz's murrelets include only surveys in the inner bay region, because few juveniles were observed in the outer bay. Numbers in (or above) the bars are the number of survey days. Note different scales on the Y-axis between plots.

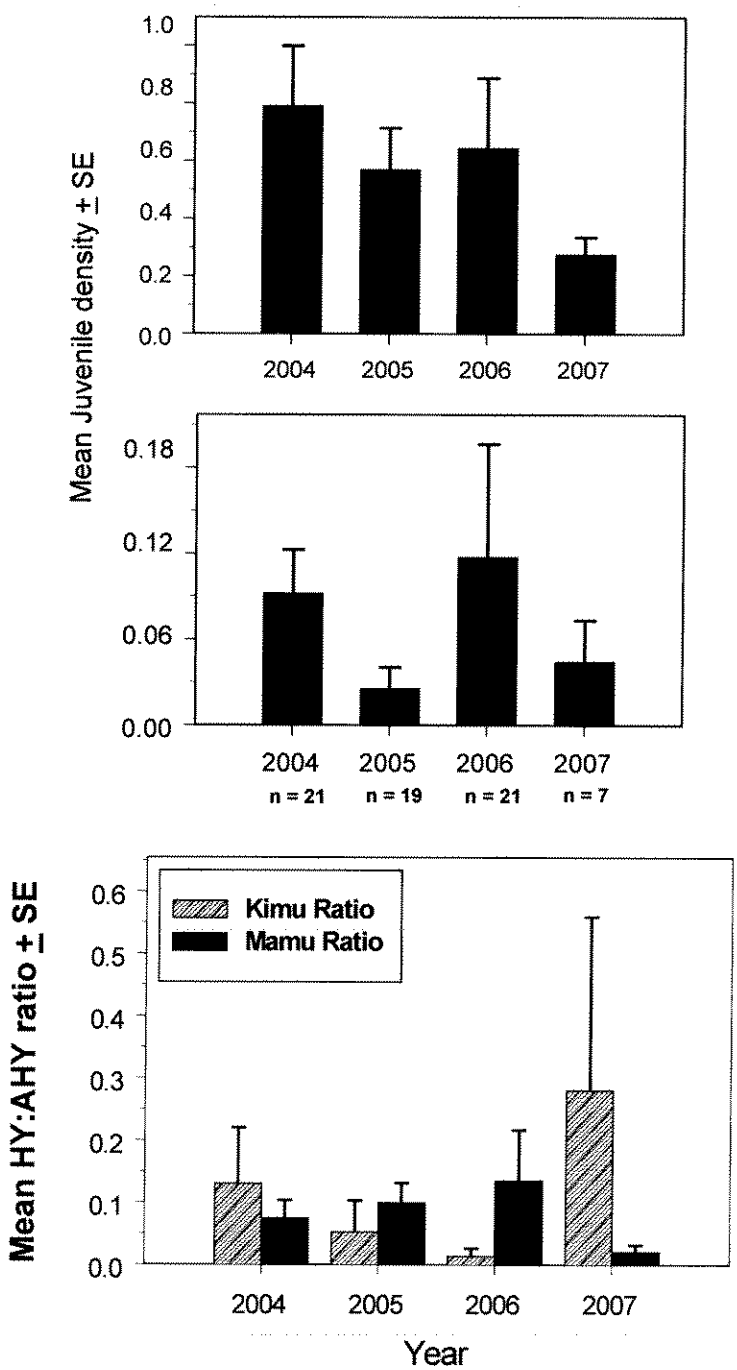
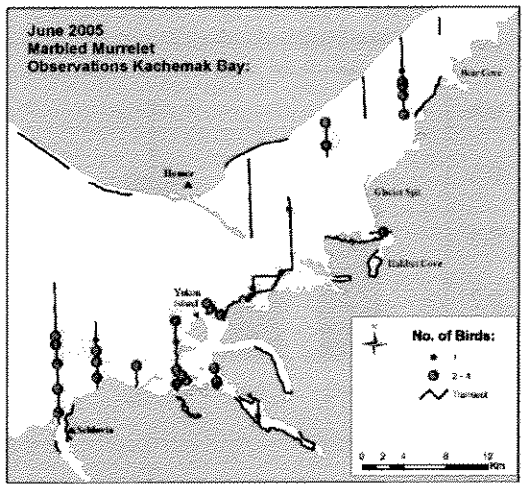
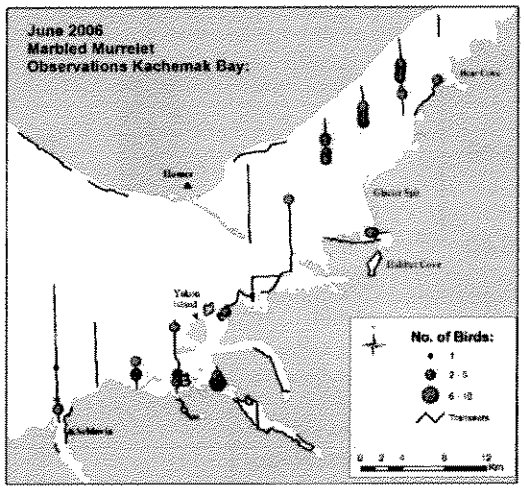


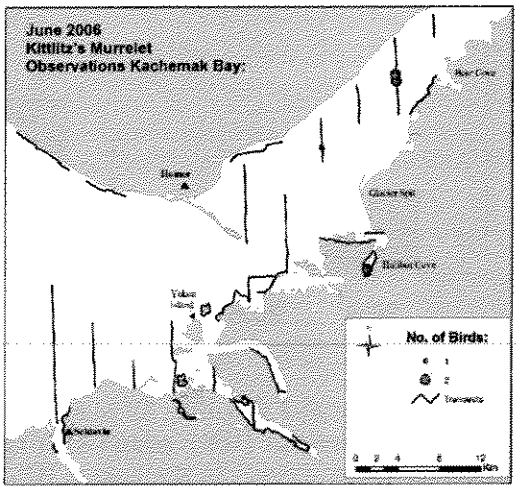
Figure 14. Juvenile murrelet densities for marbled murrelets (top), Kittlitz's murrelet (center), and juvenile (HY): adult (AHY) ratios for both species (bottom) based on at-sea surveys in Kachemak Bay during August of years 2004 – 2007. Note different scales on Y axis for juvenile densities of marbled and Kittlitz's murrelets



A



B



C

Figure 15. Distribution of marbled murrelets during Kachemak Bay surveys in June of 2005 (A) and 2006 (B), and Kittlitz's murrelets in June 2006 (C) (there were none in June 2005).

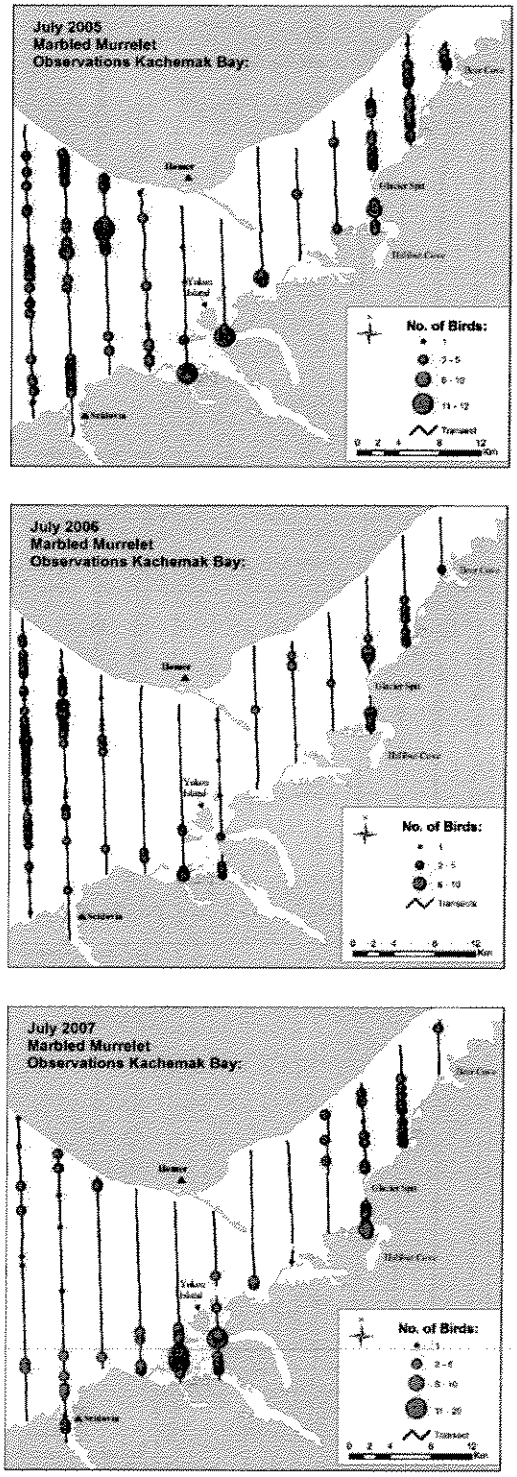


Figure 16. Distribution of marbled murrelets during surveys of Kachemak Bay between 18 – 25 July of 2005, 2006, and 2007.

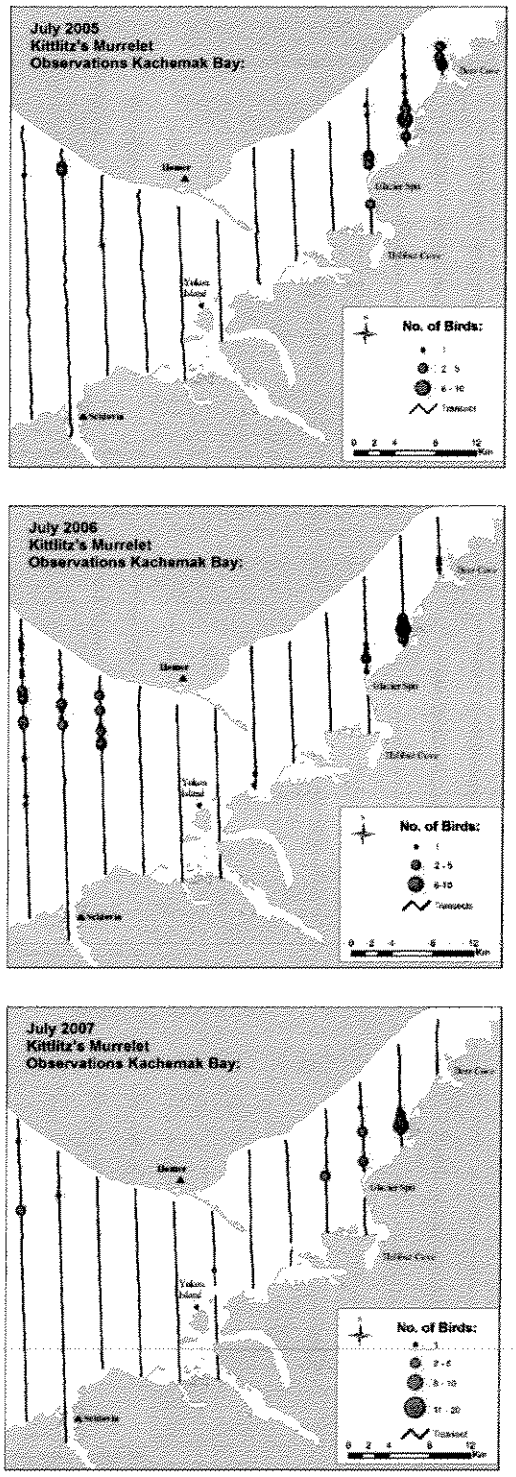


Figure 17. Distribution of Kittlitz's murrelets during surveys of Kachemak Bay between 18 – 25 July of 2005, 2006, and 2007.

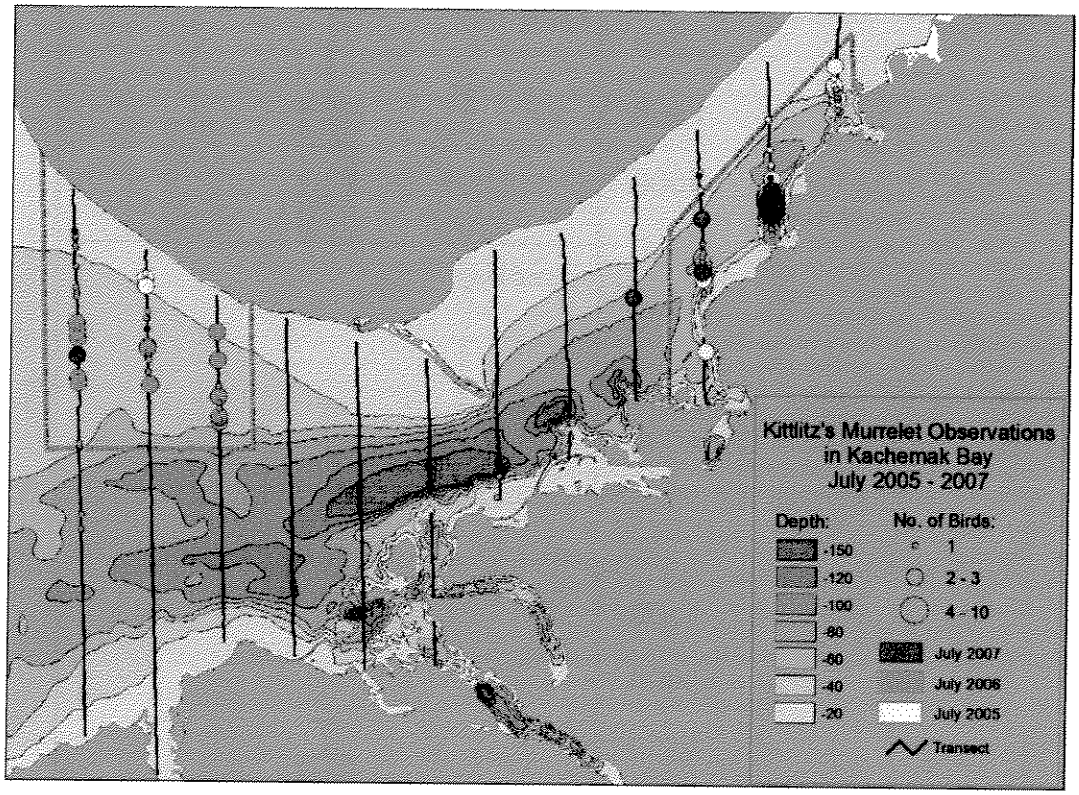


Figure 18. Combined distribution of Kittlitz's murrelets during July surveys for 2005 – 2007, with bathymetric coverage for Kachemak Bay. The two Kittlitz's murrelet hot spots are outlined in a blue dashed line. They include 128 km^2 area in the north outer bay, which was used by Kittlitz's murrelets primarily in July 2006, and a 75 km^2 area in the south inner bay, which was used all three years.

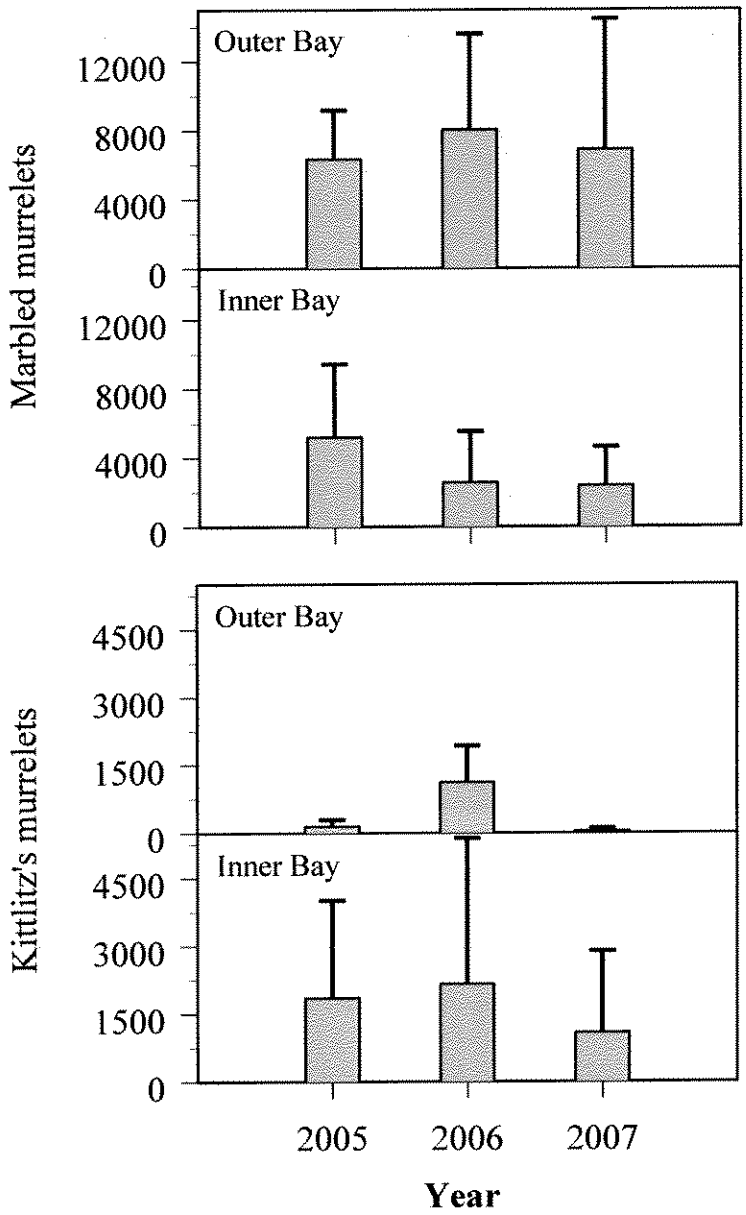


Figure 19. July population estimates (± 95% CI) for marbled murrelets (top) and Kittlitz's murrelets (bottom) by year and by regions (outer bay and inner bay). Estimates were derived from surveys conducted in Kachemak Bay, 16-26 July, 2005 – 2007.

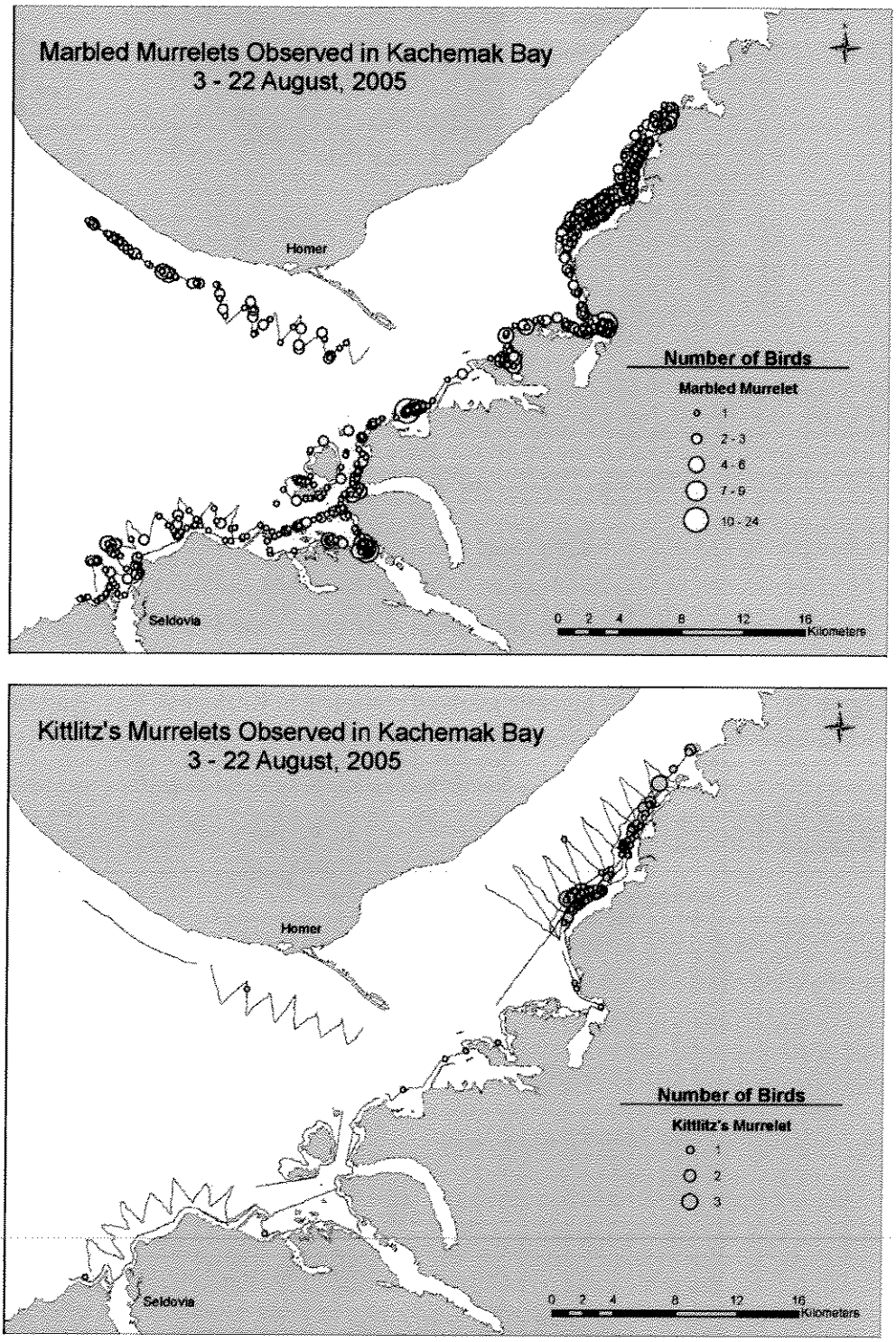


Figure 20. Distribution of marbled murrelets (top) and Kittlitz's murrelets (bottom) observed during all August surveys in 2005. Transect lines are shown in grey.

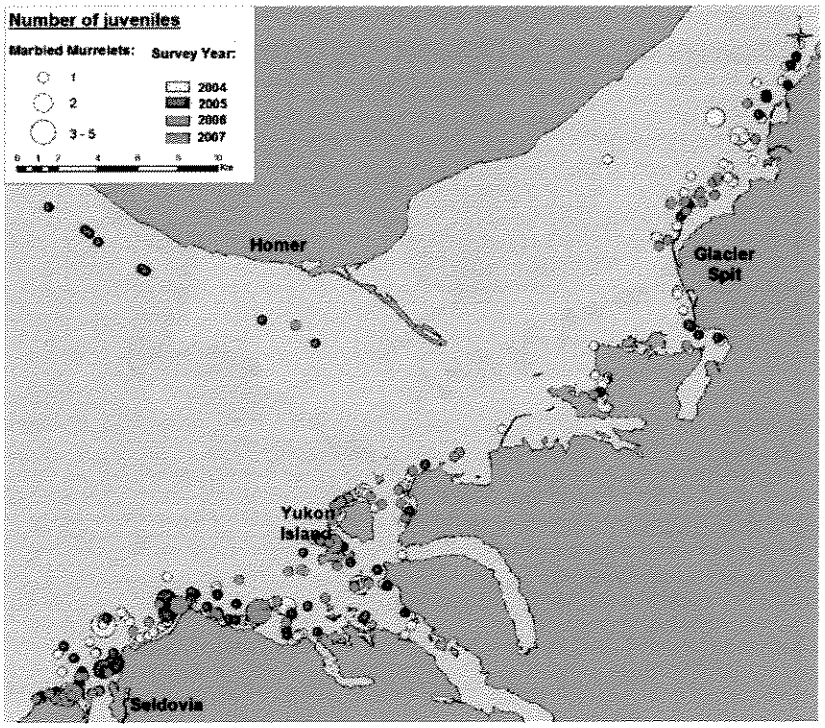


Figure 21. Distribution of juvenile marbled murrelets in Kachemak Bay, August 2004-2007.

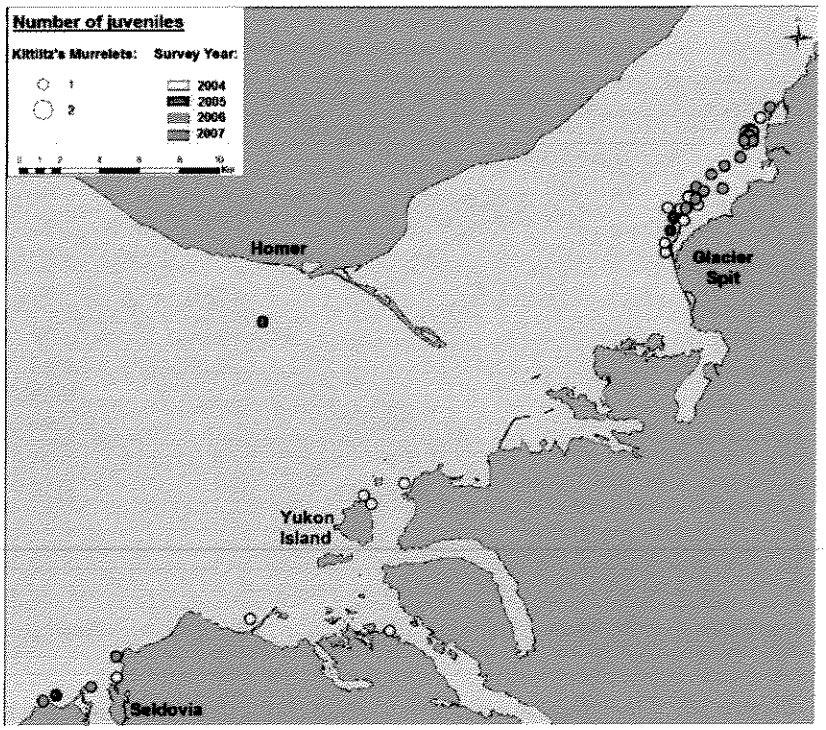
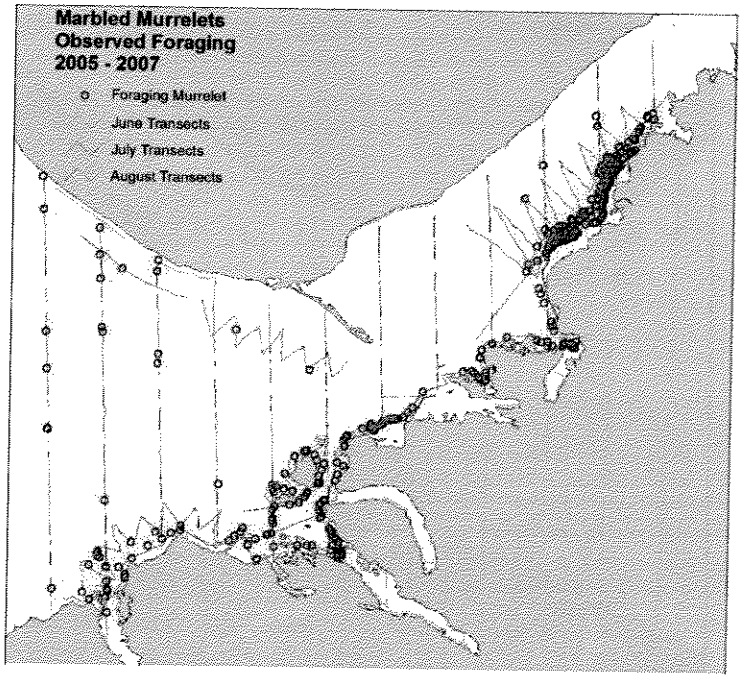


Figure 22. Distribution of juvenile Kittlitz's murrelets in Kachemak Bay, August 2004-2007.



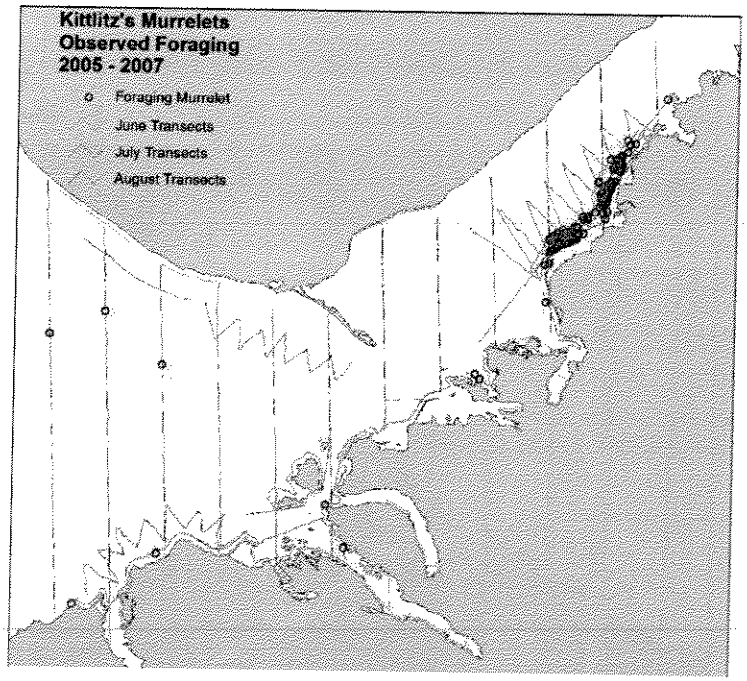


Figure 23. Location of marbled murrelets (top) and Kittlitz's murrelets (bottom) recorded as actively foraging during surveys in Kachemak Bay, June, July, and August of 2005 – 2007.

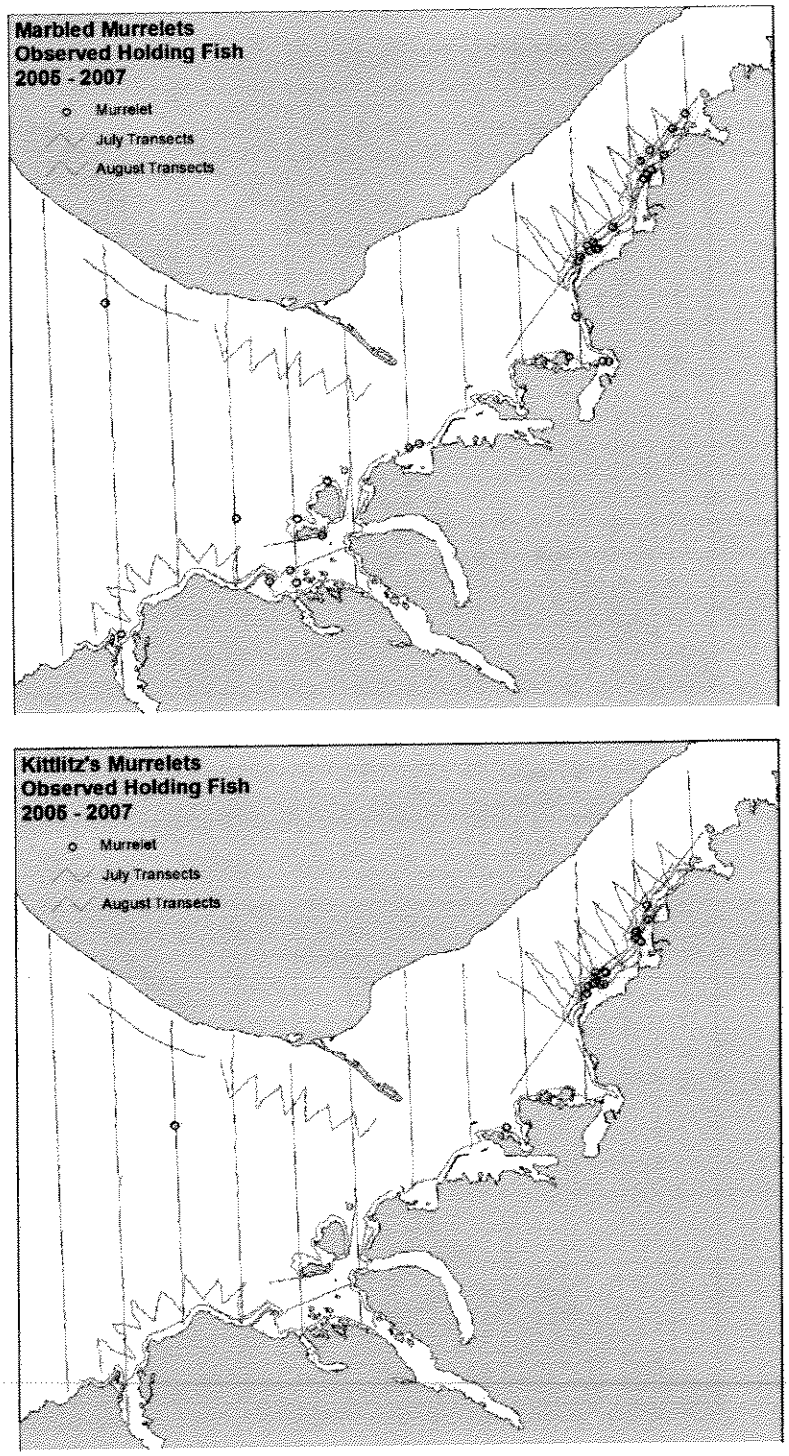


Figure 24. Observations of marbled murrelets (top) and Kittlitz's murrelets (bottom) holding fish at the surface during surveys of Kachemak Bay in July and August, 2005 – 2007.

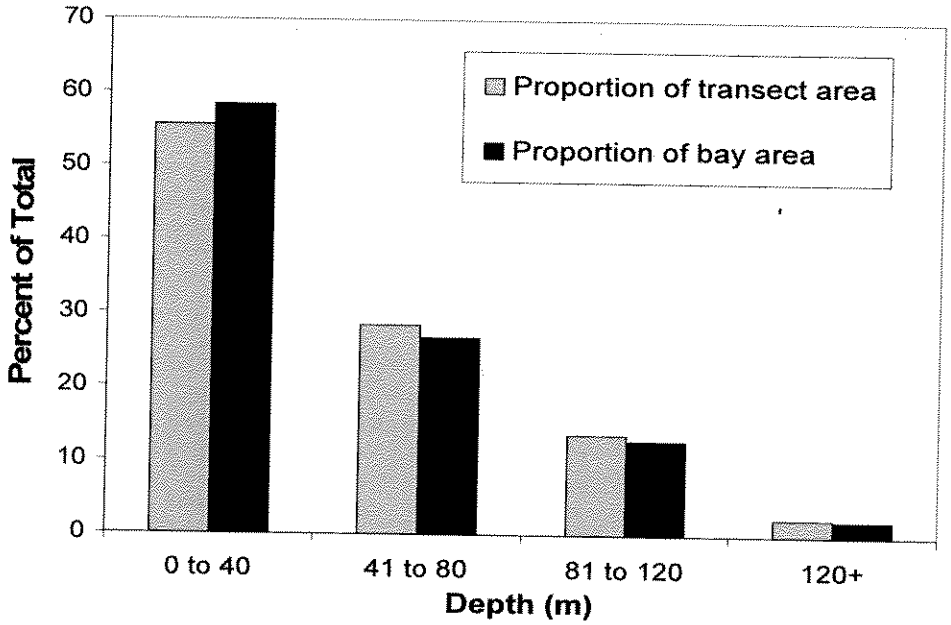


Figure 25. Proportions of water depth categories for all of Kachemak Bay (black bars) and for the area covered by survey tracks of this study in July of 2005 – 2007 (grey bars).

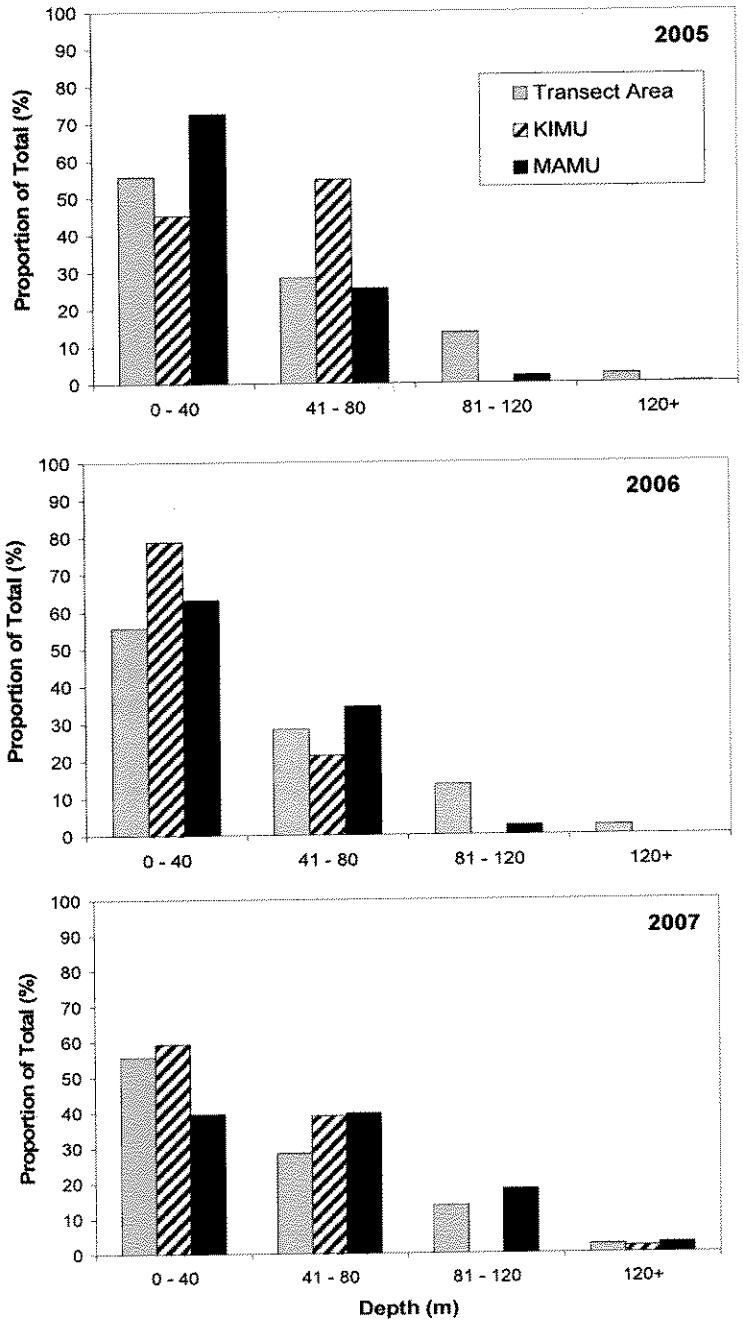


Figure 26. Proportions of water depth categories for survey transects (grey bars), Kittlitz's murrelet numbers (striped bars), and marbled murrelet numbers (black bars).

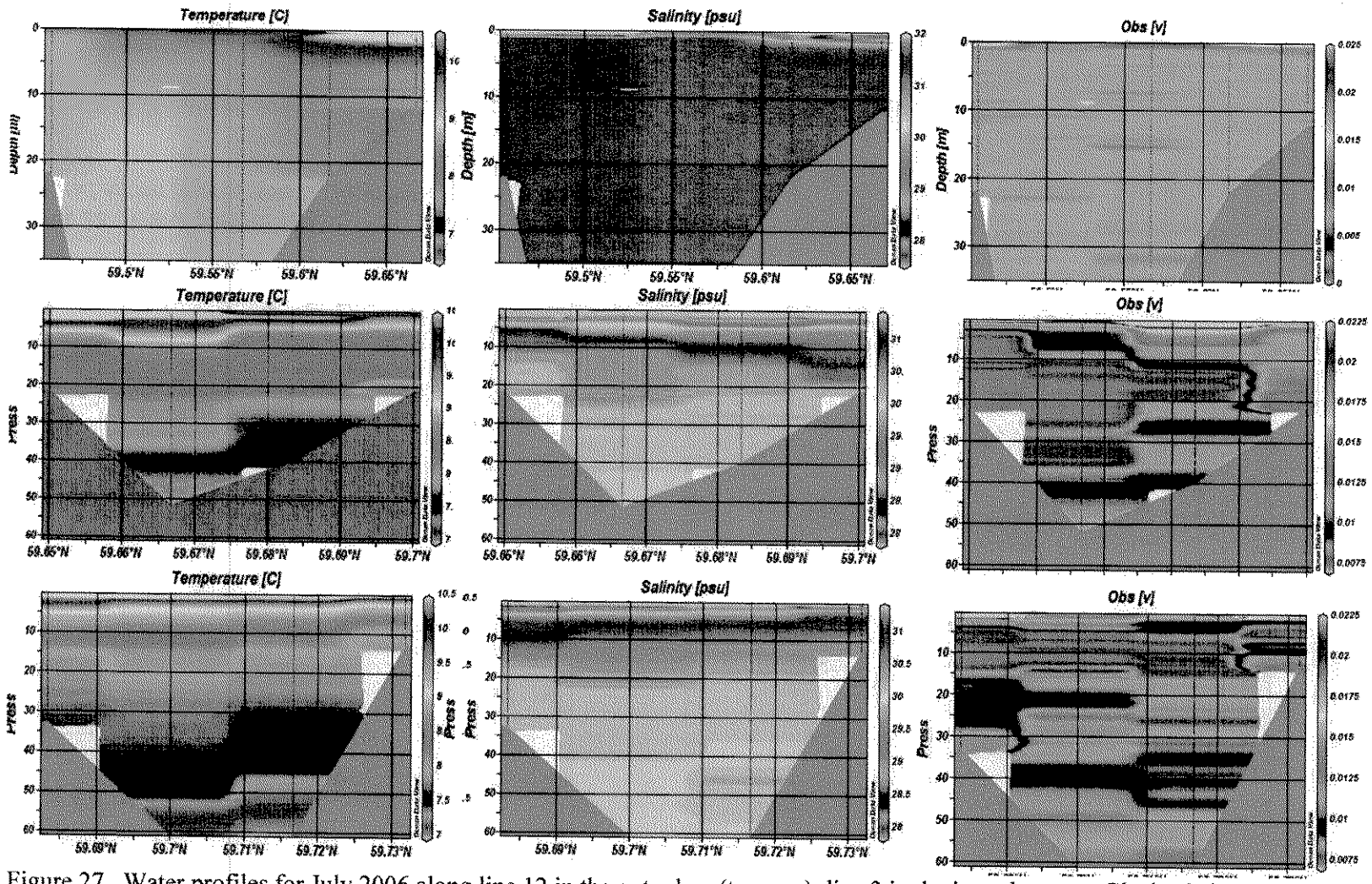


Figure 27. Water profiles for July 2006 along line 12 in the outer bay (top row), line 3 in the inner bay near Glacier Spit (middle row), and line 2 in the inner bay near Aurora Lagoon (bottom row). The north shore is on the right. Note that turbidity scale is different for line 12; it is moderately clear water.

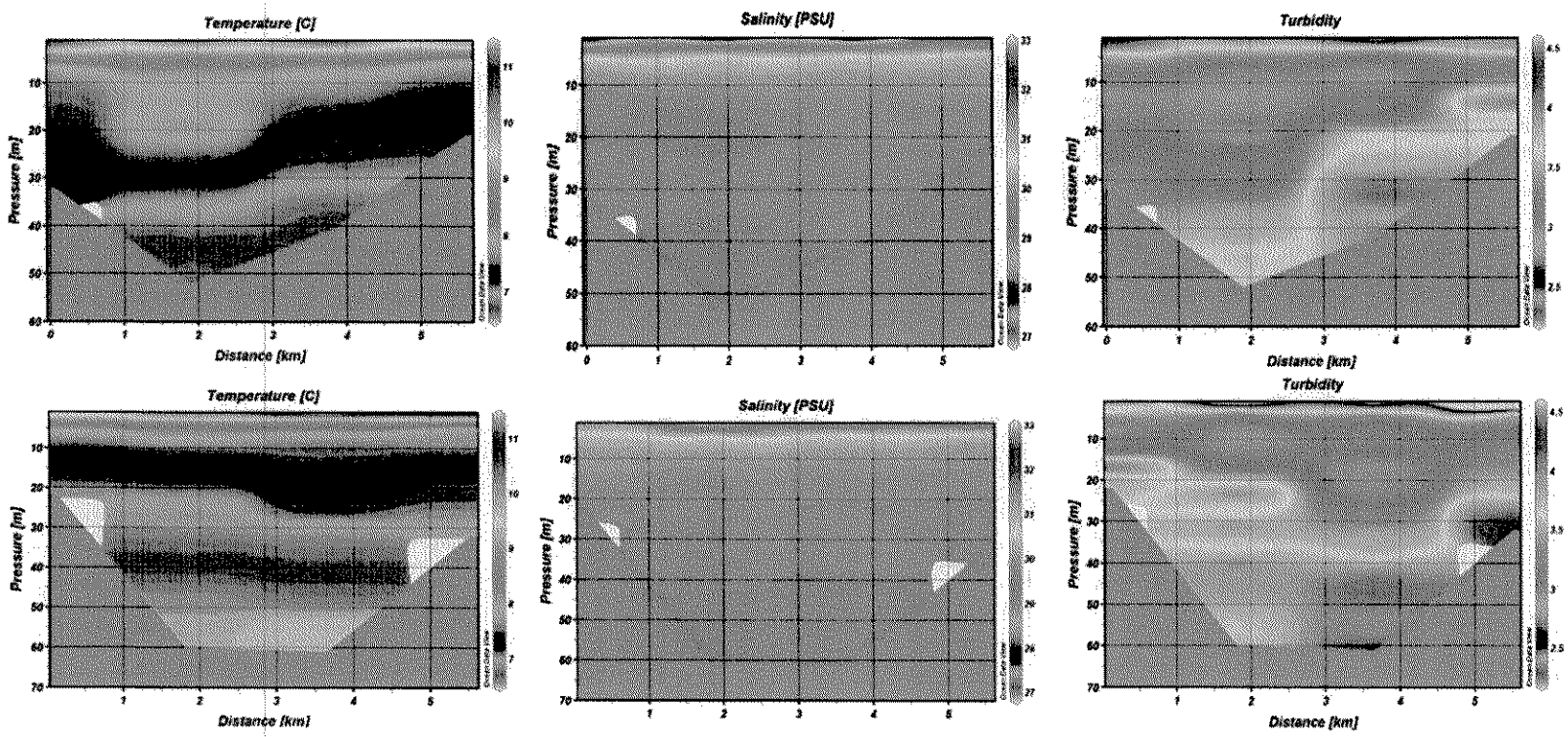


Figure 28. Water profiles for July 2007 along line 3 in the inner bay near Glacier Spit (top row), and line 2 in the inner bay near Aurora Lagoon (bottom row). The north shore is on the right.

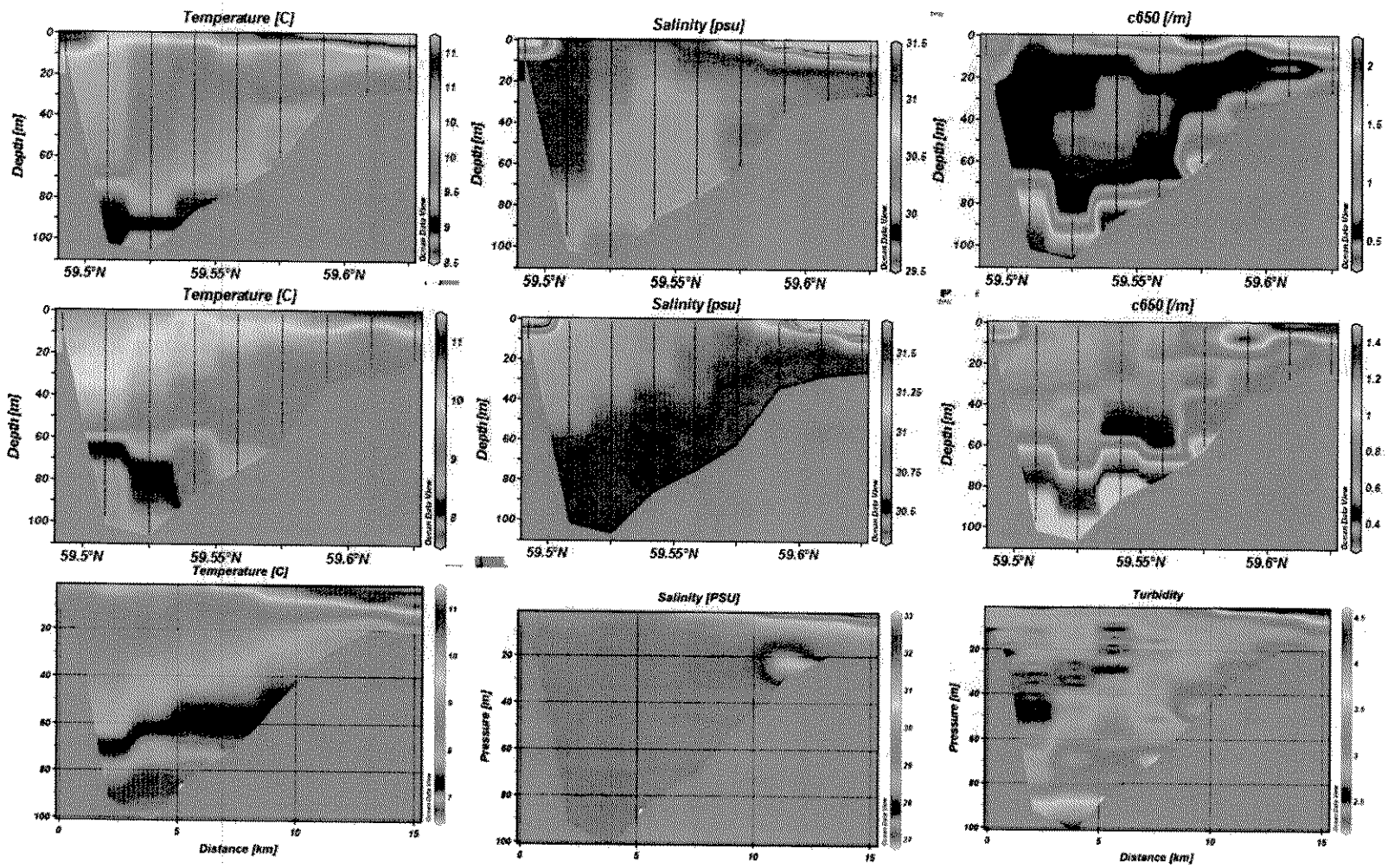


Figure 29. Water profiles along the Barabara Line, based on CTD sampling in July of 2005 (top row), 2006 (middle row), and 2007 (bottom row). Note that scales along the Y axis are different among years for turbidity (c650[/*m*]). The north shore is on the right.

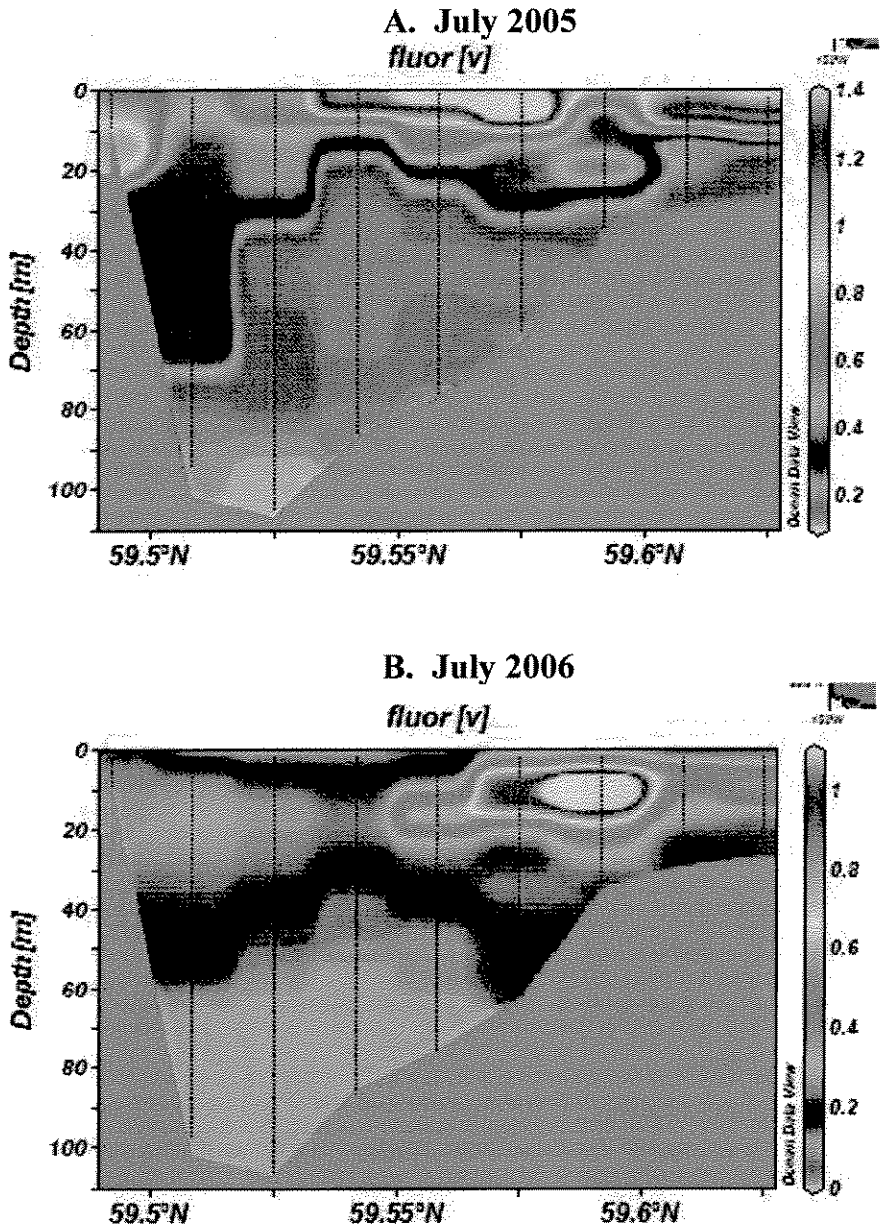


Figure 30. Fluorescence (an indicator of primary productivity) as measured by CTD casts along the Barabara Line across the mouth of Kachemak Bay in July of 2005 (A) and 2006 (B). The North Shore is on the right side of the graph. Data are from Dr. S. Pegau (formerly with Kachemak Bay National Estuarine Research Reserve). Fluorescence was not measured in 2007.

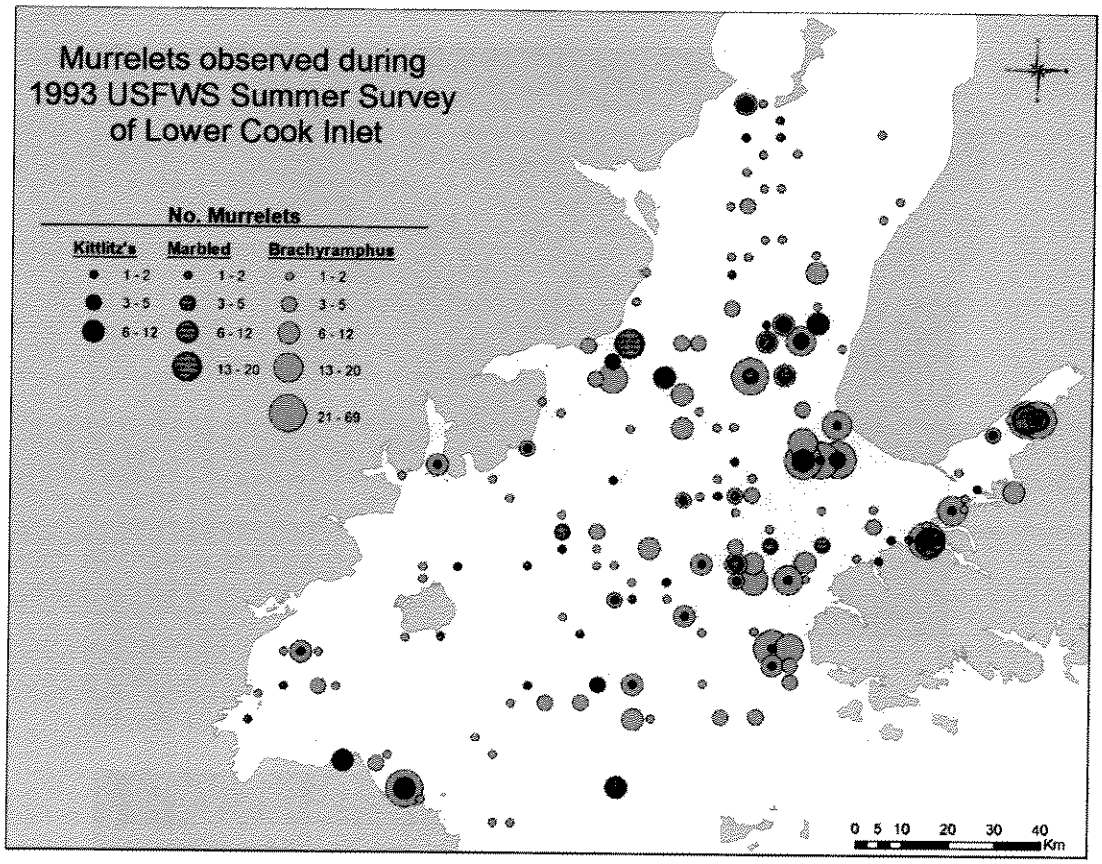
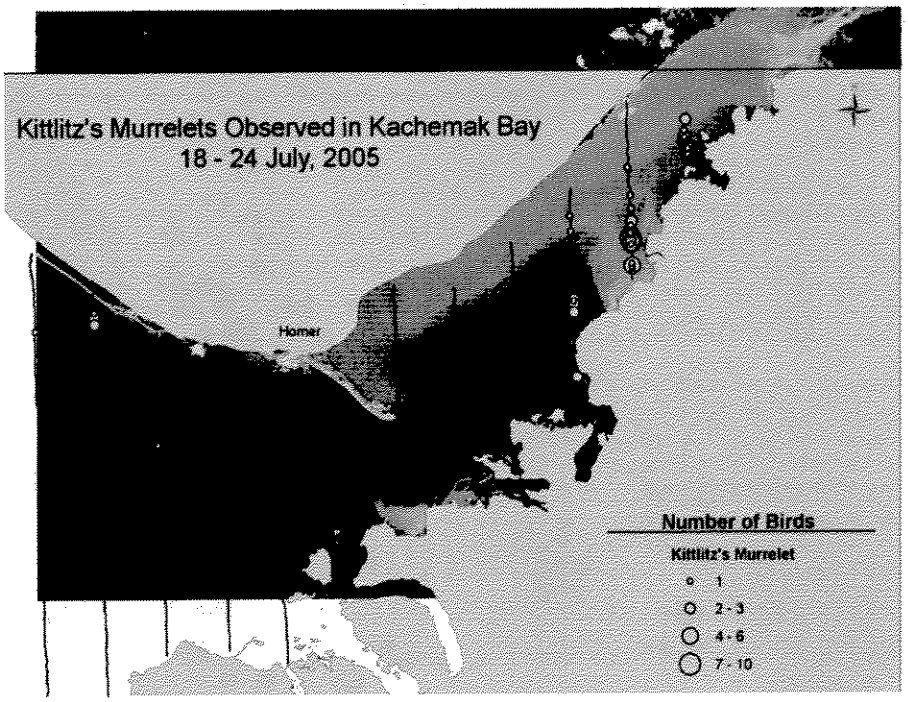


Figure 31. Distribution of marbled murrelets, Kittlitz's murrelets, and unidentified *Brachyramphus* murrelets in Lower Cook Inlet during the June 1993 survey conducted by U.S. Fish and Wildlife Service. Note the large numbers of murrelets in Kachemak Bay's inner bay, Eldredge passage, and the outer north shore at the mouth of the bay.



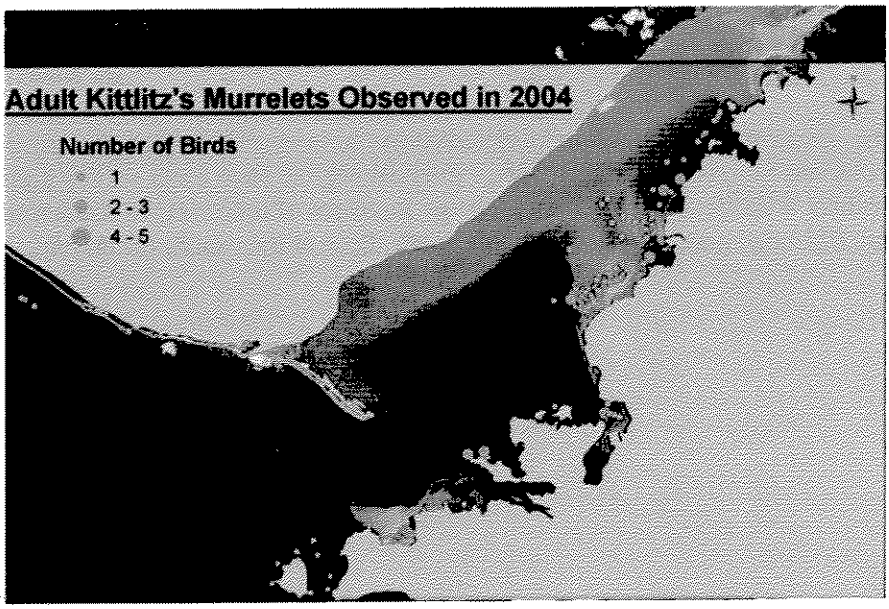


Figure 32. A satellite image of Kachemak Bay overlaid with maps of Kittlitz's murrelet observations in July (top) and August (bottom).

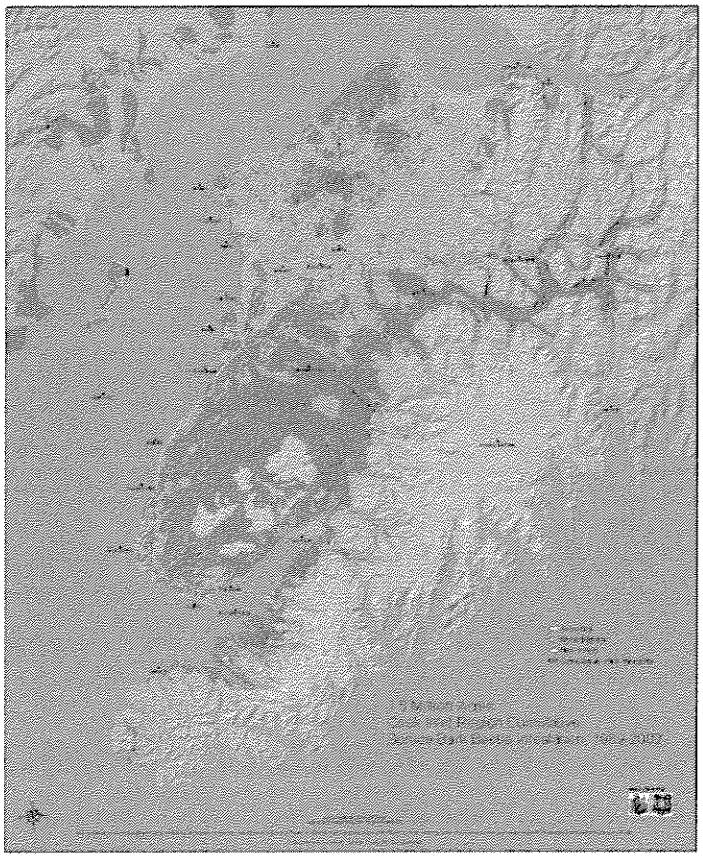


Figure 33. Cumulative Spruce Bark Beetle infestation in the Cook Inlet Region, 1989-2002. Figure provided by U.S. Forest Service, Soldotna, Alaska.

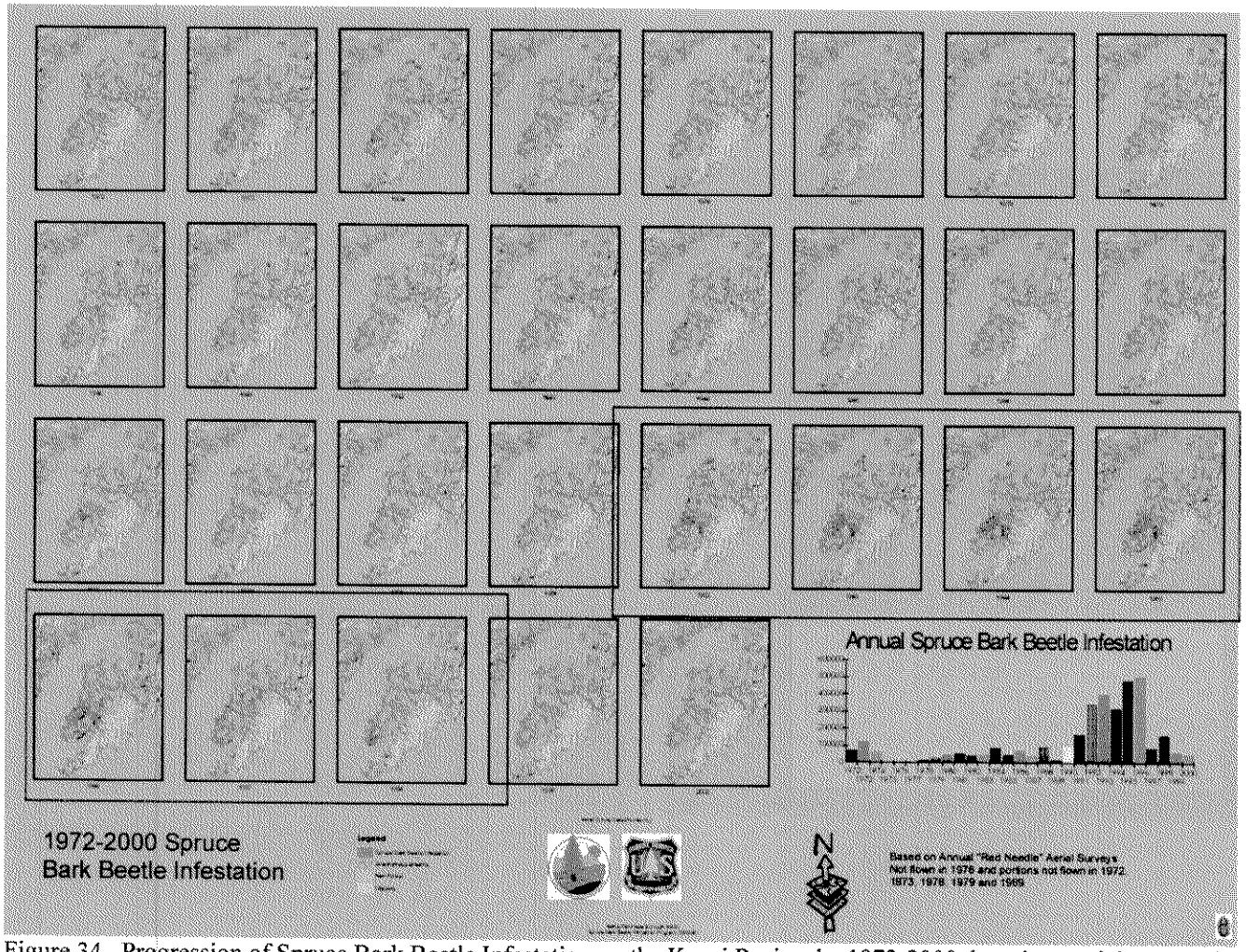


Figure 34. Progression of Spruce Bark Beetle Infestation on the Kenai Peninsula, 1972-2000, based on aerial surveys by the U.S. Forest Service. Red polygons indicate areas with new outbreak in a given year, and do not show cumulative infestation impacts. Note that the greatest 'new' infestations in the Kachemak Bay area occurred between 1992- 1998 (maps outlined in red).

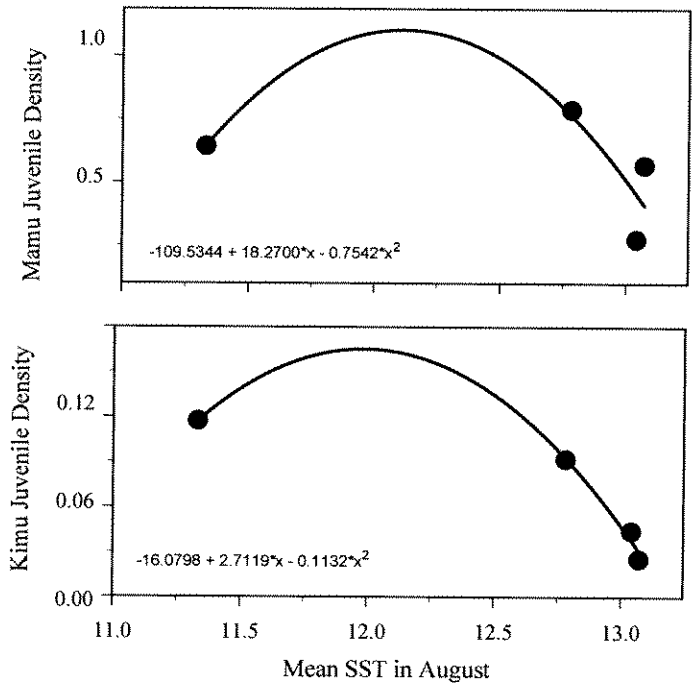


Figure 35. Mean juvenile density for marbled murrelets (top) and Kittlitz's murrelet (bottom) as a function of mean Sea Surface Temperature (SST) in August, based on surveys in Kachemak Bay, 2004 – 2007. SST values were obtained during the surveys. A polynomial curve was the best fit to the data.

Table 1. Survey effort for Kachemak Bay murrelet surveys, 2004 – 2007.

Year	Month	Survey Dates	No. Survey Days	No. Transects	Transect type	Total Area Surveyed (km^2)	Historic Source
2004	August	Aug 3-23	18	68	shoreline & zigzag	150.28	USFWS (Kuletz) & USGS (Piatt/Speckman)
2005	April	Apr 24	1	9	parallel shoreline	6.92	USFWS (Kuletz 1989, 1996)
	June	June 16-30*	5	46	shoreline & pelagic	32.56	USFWS (Agler et. al. 1995)
	June	June 20	1	4	parallel shoreline	2.7	USFWS (Kuletz 1989, 1996)
	July	July 18-23	5	12	pelagic, shore-to-shore	37.64	none
	July	24-Jul	1	9	parallel shoreline	7.95	USFWS (Kuletz 1989, 1996)
	August	Aug 3-22	17	54	shoreline & pelagic	125.86	USFWS (Kuletz) & USGS (Piatt/Speckman)
	September	Sept 2	1	5	parallel shoreline	7.11	USFWS (Kuletz 1989, 1996)
2006	June	June 17-20	4	45	shoreline & pelagic	32.55	USFWS (Agler et. al. 1995)
	July	July 18-21	4	12	pelagic, shore-to-shore	39.37	none
	August	Aug 2-23	18	66	shoreline & zigzag	128.8	USFWS (Kuletz) & USGS (Piatt/Speckman)
2007	July	July 22-25	4	12	pelagic, shore-to-shore	38.59	none
	August	Aug 8-16	7	25	shoreline & zigzag	59.64	USFWS (Kuletz) & USGS (Piatt/Speckman)
Total			86	367		669.97	

* Two inner lagoon transects that we could not access were completed by Cook Inlet Keeper on June 30.

Table 2. Densities (birds • km^{-2}) and population estimates (*N*) with 95% confidence intervals for *Brachyramphus* murrelets in Kachemak Bay during June for 1993, 2005, and 2006. The estimates shown include flying birds.

			Kittlitz's Murrelet			Marbled Murrelet			Unidentified *Brachyramphus*			Total *Brachyramphus*		
Survey	Stratum	Region	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
June 1993	Pelagic	Combined	0.42	317	447	1.18	897	1332	5.50	4170	4615	7.10	5384	5780
		Inner Bay	0.28	81	156	1.97	569	1012	5.48	1586	2377	7.73	2237	3376
		Outer Bay	0.59	279	537	0.45	209	302	5.95	2785	4625	6.99	3273	5127
	Shoreline	Combined	0.20	12	11	1.49	86	99	3.19	184	141	4.88	282	225
		Inner Bay	0.23	6	6	1.24	33	53	5.53	146	127	7.00	185	172
		Outer Bay	0.18	6	9	1.69	53	85	1.34	42	67	3.21	101	151
	All Bay			**328**	**447**		**984**	**1336**		**4354**	**4617**		**5666**	**5784**
June 2005	Pelagic	Combined	0.00	0	0	4.77	3613	1822	0.00	0	0	4.77	3613	1822
		Inner Bay	0.00	0	0	3.37	976	1089	0.00	0	0	3.37	976	1089
		Outer Bay	0.00	0	0	6.24	2924	1361	0.00	0	0	6.24	2924	1361
	Shoreline	Combined	0.00	0	0	0.66	38	32	0.00	0	0	0.66	38	32
		Inner Bay	0.00	0	0	0.65	17	23	0.00	0	0	0.65	17	23
		Outer Bay	0.00	0	0	0.67	21	23	0.00	0	0	0.67	21	23
	All Bay			**0**	**0**		**3651**	**1823**		**0**	**0**		**3651**	**1823**
June 2006	Pelagic	Combined	0.41	313	435	9.62	7292	4375	0.48	365	351	10.52	7969	4703
		Inner Bay	0.78	225	300	11.01	3187	2421	0.52	150	199	12.31	3562	2586
		Outer Bay	0.00	0	0	8.05	3772	3758	0.44	206	300	8.49	3978	4032
	Shoreline	Combined	0.11	6	10	0.33	19	22	0.00	0	0	0.33	19	22
		Inner Bay	0.30	8	13	0.90	24	27	0.00	0	0	0.90	24	27
		Outer Bay	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
	All Bay			**319**	**435**		**7312**	**4376**		**365**	**351**		**7989**	**4703**

Table 3. Densities and population estimates for *Brachyramphus* murrelets during July surveys in Kachemak Bay, 2005-2007. Calculations were done excluding flying birds, and with flying birds included, for Inner and Outer Bay regions, and combined.

		Entire Bay - Combined			Inner Bay			Outer Bay		
	July 2005	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	1.17	953	587	1.22	386	494	1.14	571	414
	Kittlitz's Murrelet	2.10	1712	2025	5.87	1854	2160	0.28	138	156
	Marbled Murrelet	13.92	11355	4546	16.54	5226	4230	12.65	6323	2856
	Total *Brachyramphus*	17.19	14020	6369	23.63	7466	6386	14.07	7032	3329
with flyers	Unidentified *Brachyramphus*	2.26	1842	856	2.36	747	726	2.21	1103	603
	Kittlitz's Murrelet	2.47	2015	2474	7.01	2214	2664	0.28	138	156
	Marbled Murrelet	14.82	12092	4506	17.28	5458	4399	13.64	6816	2682
	Total *Brachyramphus*	19.55	15949	6811	26.65	8419	7332	16.12	8057	3011
	July 2006	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	0.56	456	241	0.67	211	221	0.50	251	146
	Kittlitz's Murrelet	3.81	3108	2932	6.83	2159	3224	2.24	1119	811
	Marbled Murrelet	13.39	10919	6691	8.17	2582	2960	16.10	8045	5558
	Total *Brachyramphus*	17.76	14483	7627	15.68	4952	4995	18.84	9414	6055
with flyers	Unidentified *Brachyramphus*	1.02	829	468	1.63	516	486	0.69	347	150
	Kittlitz's Murrelet	4.04	3294	3171	7.43	2347	3486	2.28	1138	832
	Marbled Murrelet	14.02	11437	6895	9.21	2910	3506	16.52	8257	5643
	Total *Brachyramphus*	19.08	15561	8112	18.28	5773	5829	19.49	9742	6256
	July 2007	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	0.29	232	376	0.69	218	427	0.08	39	46
	Kittlitz's Murrelet	1.22	993	1640	3.44	1088	1804	0.08	39	69
	Marbled Murrelet	11.66	9511	8002	7.58	2393	2245	13.75	6872	7593
	Total *Brachyramphus*	13.16	10737	8472	11.71	3699	4111	13.91	6950	7556
with flyers	Unidentified *Brachyramphus*	1.22	993	757	2.07	653	811	0.78	392	245
	Kittlitz's Murrelet	1.40	1141	1759	3.75	1185	1941	0.20	98	93
	Marbled Murrelet	12.15	9912	8201	8.11	2563	2366	14.22	7107	7768
	Total *Brachyramphus*	14.77	12047	8840	13.93	4400	4810	15.20	7597	7670

Table 4. Summary of trends in murrelet densities, as determined by linear regressions on logged annual mean densities. Trends analysis were performed for each Transect Set in Kachemak Bay, 1988 - 2007 (see Figure 7 for graphs and Appendix C for individual transect results). For this test, only surveys conducted between 25 July and 18 August were included. Because few Kittlitz's murrelets occurred in the outer bay, we did not include analyses on Kittlitz's for that region. Because marbled murrelets were numerically dominate and species identification improved over time, the regression results for these two categories should be examined in conjunction with results for Total *Brachyramphus* murrelets.

					Percent change per year			
Region	Transect Set	Years	N years surveyed	N replicates	Kittlitz's	Marbled	Unidentified Brachyramphus	Total Brachyramphus
Inner	Inner South Shore	1988 - 2007	9	14	- 4	+ 11	- 12	0
Inner	Inner Zigzag	1996 - 2005	6	6	- 18	0	- 14	- 4
Outer	Eldredge Passage	1988 - 2006	4	10	na	+ 2	- 23	- 6
Outer	Outer North Shore	1996 - 2006	6	7	na	+ 14	0	+ 8
Outer	Outer South Shore	1996 - 2007	7	13	na	+ 9	+ 21	+ 8
Outer	Outer Zigzag	1996- 2006	5	8	na	+8	- 30	+ 6

na = not applicable

Table 5. Mean densities (birds • km^{-2}) for murrelets in Kachemak Bay during late summer surveys (25 July - 18 August) for two decadal periods, 1988 - 1999 and 2004 - 2007. Daily surveys were combined by period and region. KIMU = Kittlitz's murrelets, MAMU = marbled murrelets, Unid BRMU = *Brachyramphus* murrelets not identified to species, All BRMU = identified and unidentified murrelets combined. Significant results are in bold. Between decadal periods there were significant declines in Kittlitz's murrelets for the Inner bay and the entire bay, and a significant increase in total murrelets for the Outer bay.

		Survey effort		Mean (± SE)			
Period	Region	N years	replicates	KIMU	MAMU	Unid BRMU	All BRMU
1988-1999	all bay	6	19	**5.50 (2.22)**[a]	13.29 (3.24)	10.00 (3.2)	28.80 (6.87)
2004-2007	all bay	4	18	**3.11 (1.87)**	20.44 (4.36)	1.97 (0.82)	25.51 (6.49)
1988-1999	Inner	6	9	**11.37 (3.90)**[b]	22.28 (5.31)	16.71 (4.57)	50.36 (9.43)
2004-2007	Inner	4	6	**9.09 (5.01)**	36.86 (9.04)	4.77 (2.08)	50.73 (14.30)
1988-1999	Outer	5	10	0.22 (0.20)	5.19 (1.39)	3.95 (3.41)	**9.39 (4.48)**[c]
2004-2007	Outer	4	12	0.12 (0.05)	12.22 (2.65)	0.57 (0.17)	**12.91 (2.80)**

[a] Wilcoxon Rank Sum test between periods; $Z = -2.63$, $P = 0.009$

[b] Wilcoxon Rank Sum test between periods; $Z = -2.57$, $P = 0.01$

[c] Wilcoxon Rank Sum test between periods; $Z = 4.71$, $P < 0.01$

Table 6. Kittlitz's murrelet and marbled murrelet juvenile density (mean ± SE) and juvenile:adult ratios (mean ± SE) in Kachemak Bay, derived from August surveys, 2004 - 2007.

Year	N survey days		Juvenile Densities (Mean ± SE)					
			Kittlitz's murrelets			Marbled murrelets		
	Inner	Outer	Inner	Outer	All bay	Inner	Outer	All bay
2004	11	10	0.12 (0.05)	0.06 (0.04)	0.09 (0.03)	0.32 (0.10)	1.30 (0.38)	0.79 (0.21)
2005	9	10	0.03 (0.03)	0.02 (0.02)	0.03 (0.02)	0.27 (0.11)	0.84 (0.23)	0.57 (0.15)
2006	9	12	0.26 (0.18)	0.01 (0.01)	0.12 (0.08)	0.23 (0.06)	0.95 (0.41)	0.64 (0.25)
2007	4	3	0.03 (0.03)	0.06 (0.06)	0.04 (0.03)	0.22 (0.03)	0.35 (0.14)	0.27 (0.06)

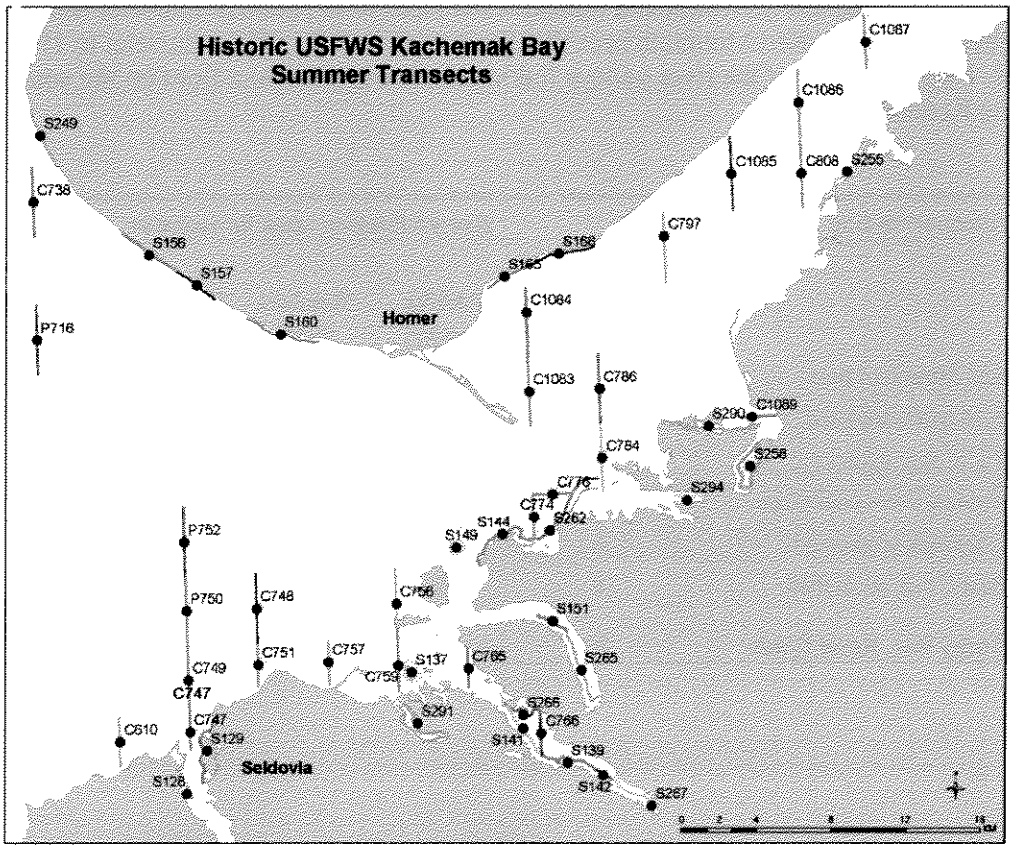
	N survey days		Juvenile:Adult ratios (Mean ± SE)					
			Kittlitz's murrelets			Marbled murrelets		
	Inner	Outer	Inner	Outer	All bay	Inner	Outer	All bay
2004	11	10	0.049 (0.02)	0.219 (0.19)	0.13 (0.09)	0.011 (0.00)	0.145 (0.06)	0.07 (0.03)
2005	9	10	0.004 (0.00)	0.096 (0.10)	0.05 (0.05)	0.013 (0.01)	0.178 (0.05)	0.10 (0.03)
2006	9	12	0.032 (0.03)	0	0.01 (0.01)	0.008 (0.00)	0.230 (0.14)	0.13 (0.08)
2007	4	3	0.003 (0.00)	0.652 (0.65)	0.28 (0.28)	0.006 (0.00)	0.041 (0.02)	0.02 (0.01)

Table 7. Mean (± SE) water surface variables measured on site prior to each transect surveyed in Kachemak Bay, 2004 – 2007. SST = sea surface temperature.

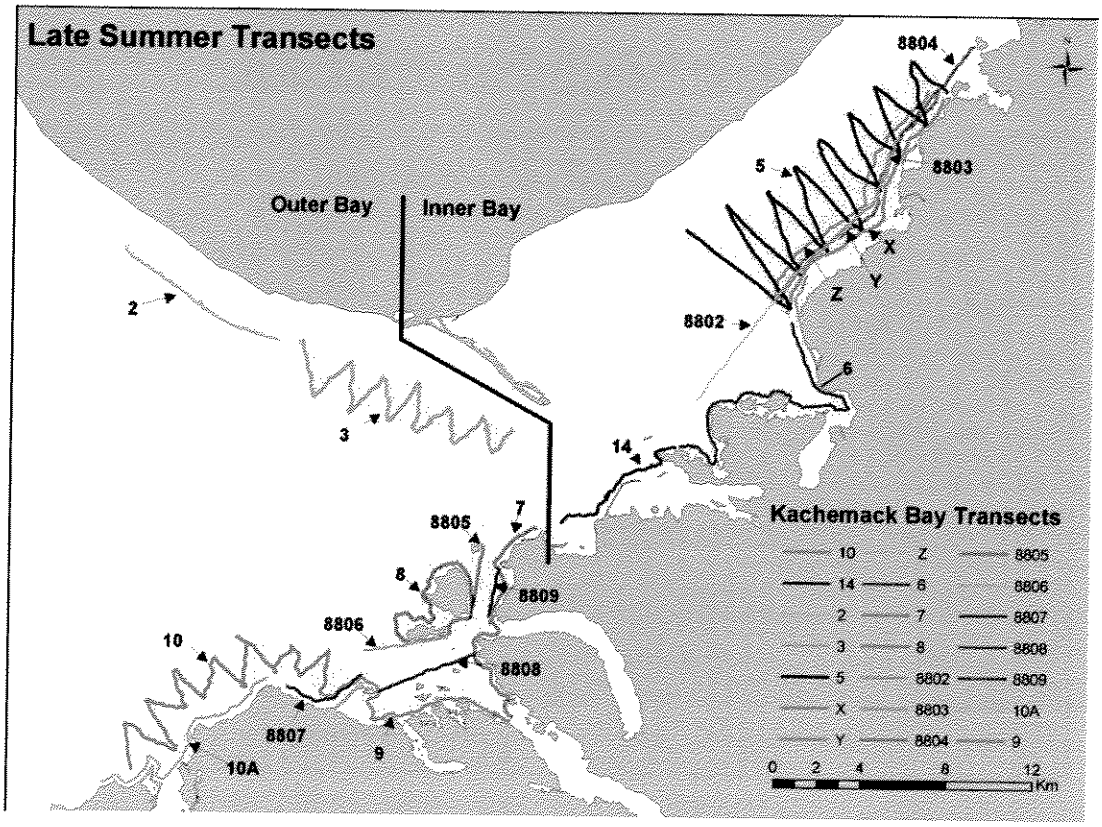
Month	Year	N	SST (°C)		Salinity (ppu)		Secchi depth (m)	
			x	*SE*	*x*	*SE*	*x*	*SE*
April	2005	8	5.2	0.1	30.4	0.3	3.8	0.6
June	2005	49	11.0	0.2	26.9	0.7	2.9	0.3
	2006	43	8.9	0.2	26.9	0.6	3.8	0.4
July	2005	54	12.8	0.2	25.7	0.7	4.2	0.4
	2006	49	10.7	0.2	27.9	0.4	3.9	0.4
	2007	36	11.0	0.2	27.6	0.5	3.1	0.2
August	2004	83	12.8	0.1	26.4	0.4	4.1	0.3
	2005	67	13.1	0.2	26.8	0.4	4.5	0.3
	2006	72	11.3	0.1	26.1	0.6	4.1	0.3
	2007	25	13.0	0.3	26.0	0.7	3.5	0.4
September	2005	5	12.9	0.2	25.4	0.8	4.0	0.7

Table 8. Approximate distances (kilometers) in Kachemak Bay between marine areas used by *Brachyramphus* murrelets and upland watersheds with potential murrelet nesting habitat. Sites include the Red Mountain nest site discovered for a Kittlitz's murrelet in 1993 (Piatt et al. 1999), and one of the river valleys linking Kachemak Bay to a fjord on the south side of the Kenai Peninsula.

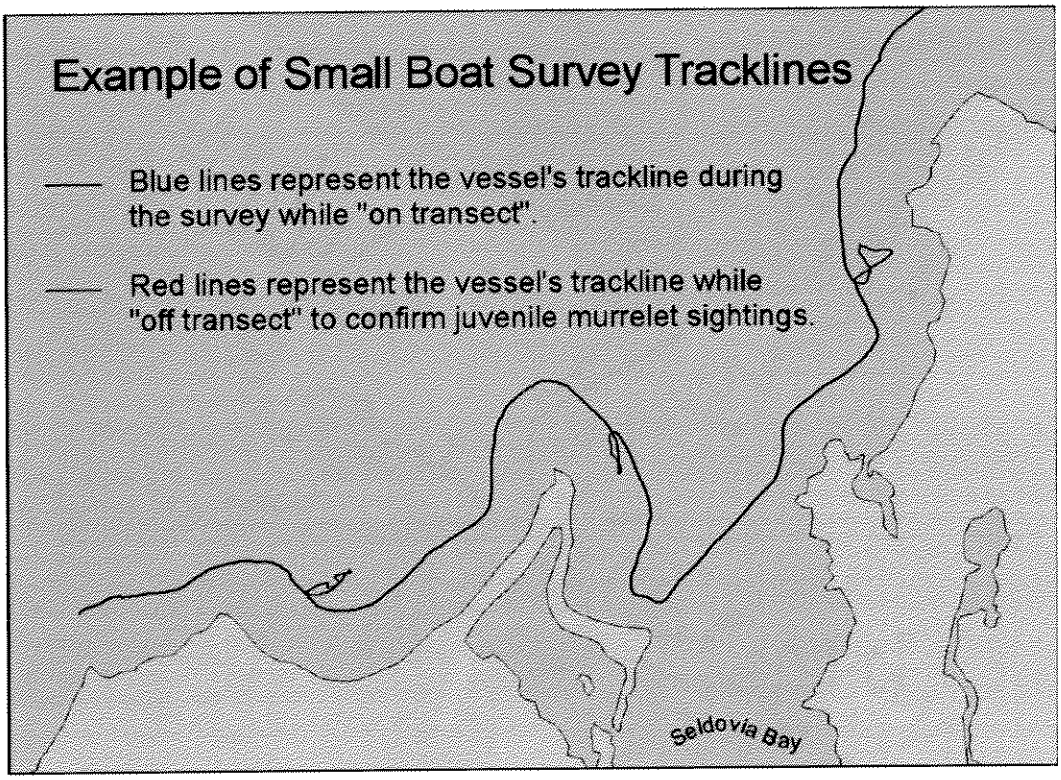
Potential Nesting Areas	Known foraging areas for murrelets				
	Inner Bay (Aurora Lagoon)	Eldredge Passage	Barabara Point	North shore shelf	North outer bay (off Anchor Point)
Red Mountain nest	42	17	16	33	42
Seldovia watershed	44	19	10	24	36
Tutka Bay watershed	30	4	10	17	35
Halibut Cove watershed	12	19	30	31	48
Grewingk watershed	6	24	35	34	52
Bear Cove watershed	8	33	44	41	56
Rocky Bay, Kenai fjords	26	10	10	23	35



Appendix A-1. Randomly selected transects from the 1993 FWS survey of Lower Cook Inlet that fell within Kachemak Bay. Transects are labeled with the original transect numbers used in FWS database. The first letter denotes the strata of the transect: P = pelagic, C = coastal pelagic, S = shoreline.



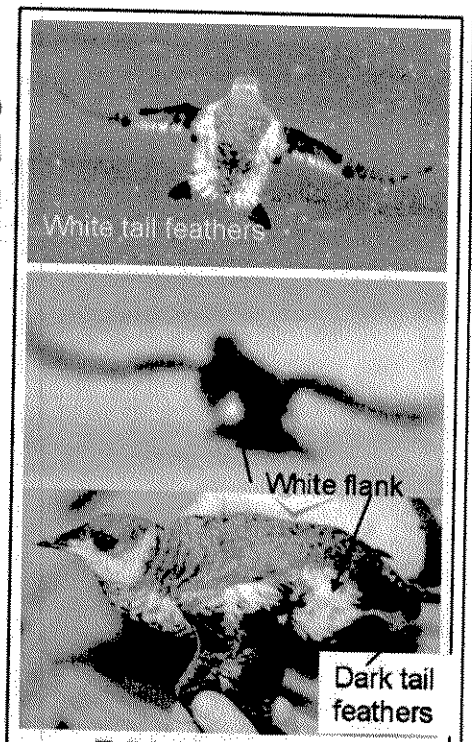
Appendix A-2. Location and reference numbers for late summer transects. These transects had both historic (see Appendix x) and recent (2004-2007) surveys. Murrelet densities for individual transects during the 2004-2007 surveys are in Appendix C.



Appendix B-1. Example of survey trackline during August juvenile surveys, showing 'off transect' portion in red.

Kittlitz's

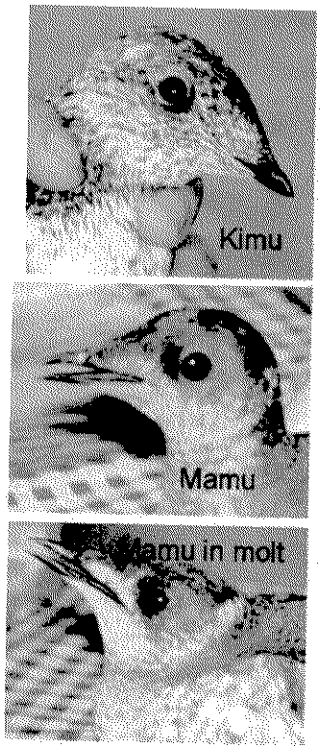
Marbled



Tail feathers

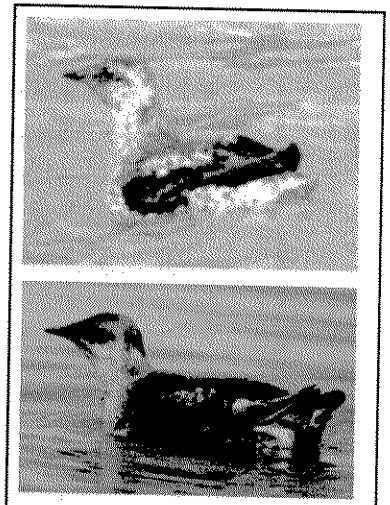
Kimu – white outer tail feathers, & white on flanks & vent.

Mamu – dark tail; don't confuse with white flanks & white vent (white vent visible with tail cocked up or as it dives – same as Kimu)



Kimu – fine streaking, or 'salt & pepper' look; blunt head shape, tiny bill.

Mamu – dark below eye, more uniform dark (or white patches if molting), longer slender bill.

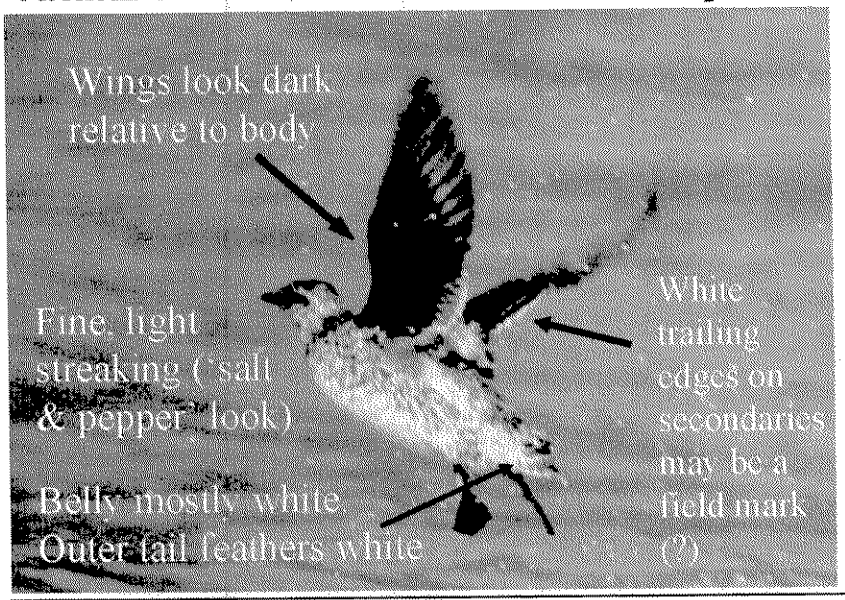


Kimu – light grey or tawny/golden (varies with light). Wings may darkly contrast with light body. Eye prominent & large. Rarely vocalizes ('croaks' like a puffin)

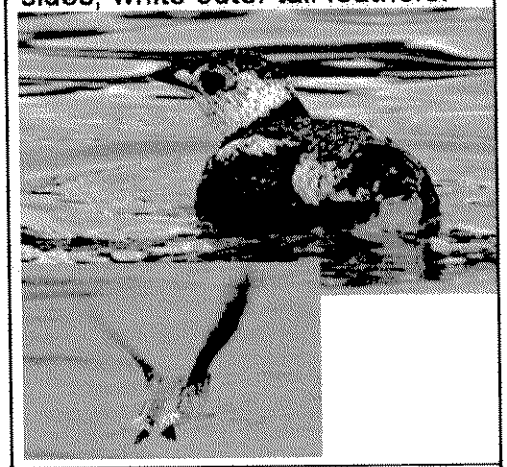
Mamu – dark overall, or pale neck & belly; can have white blotches or 'marbling'. White vent shown when diving. Often vocal – high piercing 'keer keer' call (more like a mew gull than puffin).

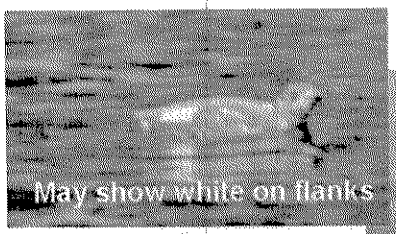
Appendix B-2. Field guide for distinguishing Kittlitz's and marbled murrelets, page 1.

Kittlitz's murrelet - easiest to identify when it is taking off from water

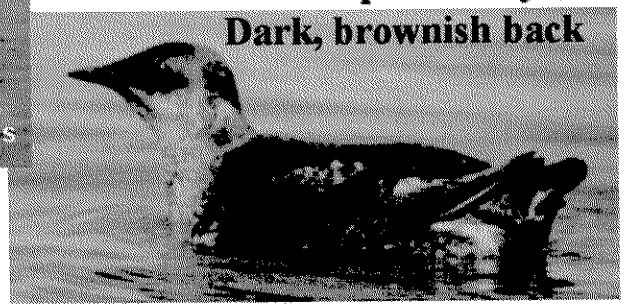


Light back, 'salt & pepper' along sides, white outer tail feathers.





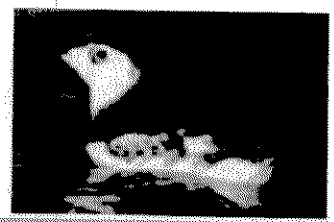
Longer head profile; longer bill



Marbled murrelet – more uniform dark chocolate color, or more 'blotchy' than fine streaking. Can be paler along neck & breast. Dark cap usually prominent below eye.

Appendix B-2. Field guide for distinguishing Kittlitz's and marbled murrelets, page 2.

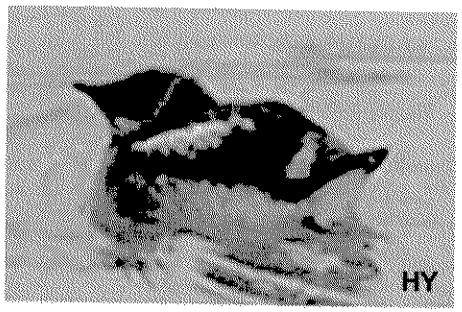
AHY ?



The black/white barring on outer tail feathers may be diagnostic. This bird still had an egg tooth, was very small, was a weak diver, and did not fly.

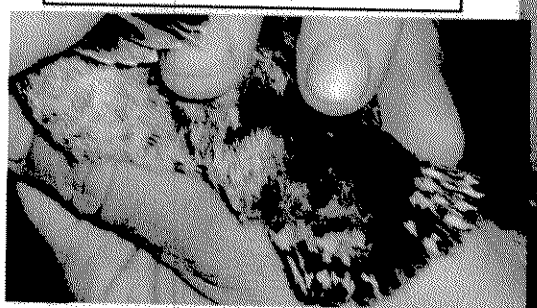
Kittlitz's Juveniles: Limited documentation suggested juveniles might range from black & white (similar to winter) plumage (top left), to dark grey with white contrasts (middle left). But, we observed that newly fledged juveniles have a 'smudgy' grey appearance & no clean white on face. Bird on right (PWS, July 2004) is a confirmed juvenile. Note dark 'smudged' appearance, perhaps newly fledged.

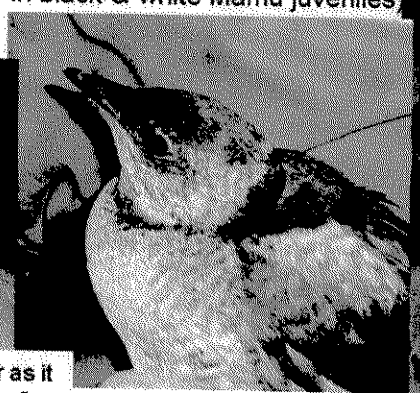
Bird at left acted like a juvenile, but has white in front of eye, and brown on wings. Possibly a transitional AHY. But, transitional phases of older juveniles are not well described.



HY

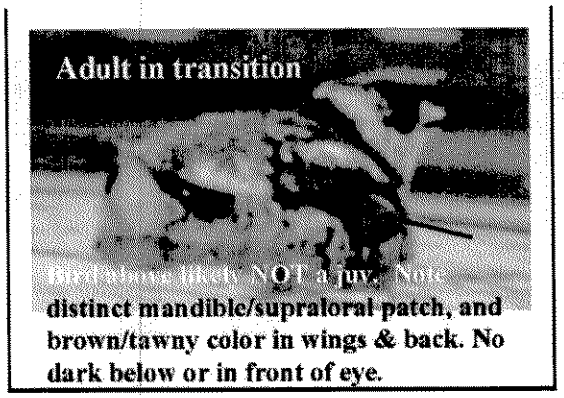
The Kittlitz's juvenile (below & upper right) was caught in PWS July 28, 2004. Although it had a contrasting dark/white plumage that caught your eye from a distance, up close it's plumage was dark grey and smudgy around head and breast. It had a distinct neck ring (also seen in black-&-white Mamu juveniles)

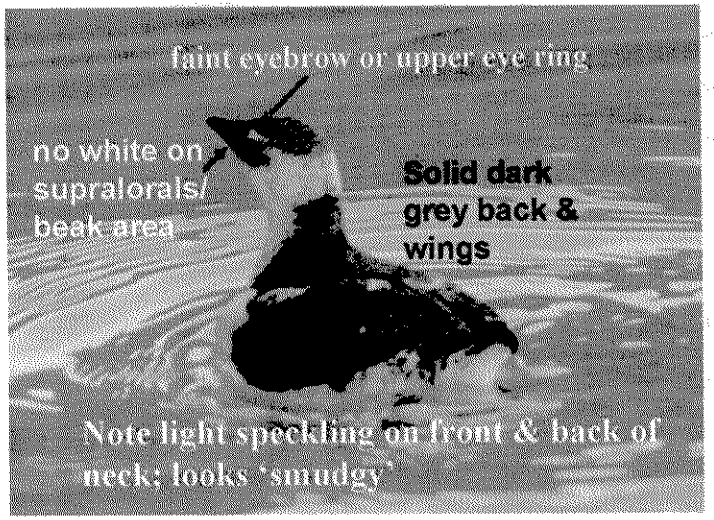




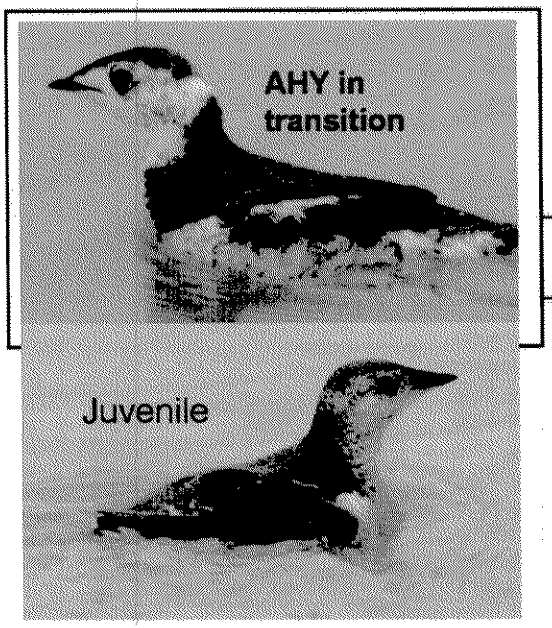
This barring can be seen as the bird takes off, or as it tries to fly. Older fledglings may be more likely to fly.

Appendix B-2. Field guide for distinguishing juvenile and adult Kittlitz's murrelets, page 1.

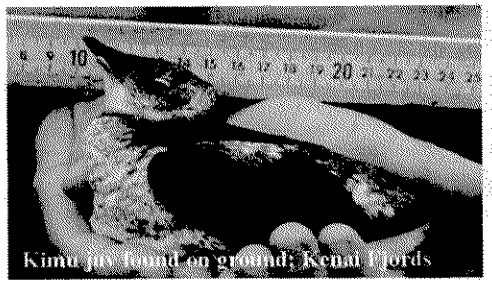




Kimu juv in Icy Bay, SEAK, 2005 (by M. Reid)



Note that some non-juveniles (in transition) may also refuse to fly, and their behavior can be similar to juveniles



Note heavy speckling on chin, breast, belly, wing patches. Also, dark necklace when hunched.

Of all definite juveniles (in hand), none had white on upper mandible or brown on wings/back.

Appendix B-2. Field guide for distinguishing juvenile and adult Kittlitz's murrelets, page 2.

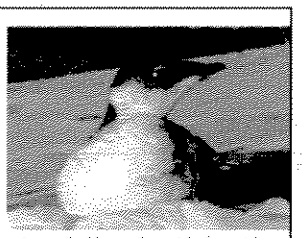
MARBLED MURRELETS

ID GUIDE for JUVENILES

No strong white above mandible. Dusky speckling on neck or breast, with evident 'necklace' (formed when they scrunch up neck).

Small size, especially beak. This is relative, but noticeable when seen with adults, or up close.

Note also small white 'eyebrow' (or eyelid?), which is often visible on juveniles.

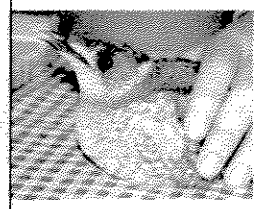


Juvenile Mamu found in forest in Kodiak.

Photo by Denny Zwiefelhofer

Usually poor divers & flyers; attempt to fly, but can't, or make shallow, brief dives (but may manage to disappear from view anyway).

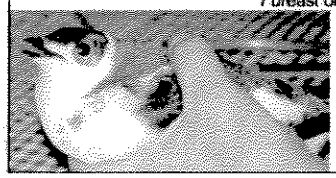
Adult Mamu caught in June.



Both birds had brood patches.

Top: in transition, but not uncommon in breeding birds in Alaska.

Bottom: bird in basic. Note large blotches on white breast – common in basic adults, as opposed to fine speckling on neck / breast of juveniles.

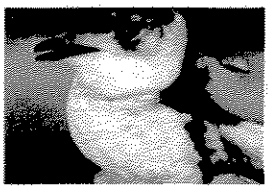


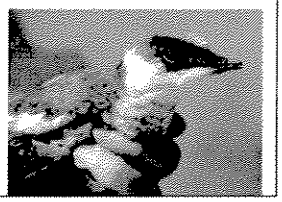
Both: note large white patch on upper mandible area (feathered area between eye and mandible).

Mamu Juveniles:

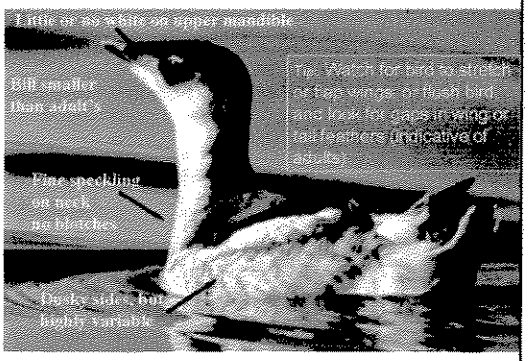
Left (same bird), from nest in PWS. Below, from different nest. **Note:**

- fine speckling on neck / breast
- dusky patch between eye & upper mandible
- small beak (remnants of egg tooth visible).



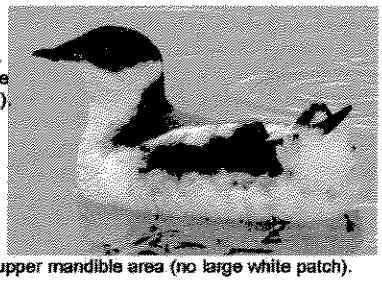


Juvenile marbled murrelet



Mamu at Kodiak on 14 Feb, 2004. (But still looks like a hatch-year bird).

Photo by Rich MacIntosh



Note:

- Faint patch on upper mandible area (no large white patch).
- Fine speckling on neck and breast (no blotches).
- Relatively small beak (egg tooth gone).
- If wings or tail spread out, would be no gaps & feather tips would be clean, pointed.

Mamu – AHY (after-hatch-year bird), late May, Auk Bay

Photo by Gus van Vliet.

- Large white patch on upper mandible area.
- Large dark blotches on neck / breast (not fine speckling).
- Could be a 1-yr old ? (prominent neck band & late molt).
- If wings or tail spread out, likely would notice gaps (from missing feathers) or ragged, 'weathered' feather tips.

Appendix B-2. Field guide for distinguishing juvenile and adult marbled murrelets.

Appendix C-1. Murrelet numbers and densities during Kachemak Bay surveys in June of 2005.

June 2005				**No. of observed murrelets**				**Murrelet Density** (birds/km^2)			
Region	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	C1083	17-Jun-05	0.72	0	0	0	0	0.00	0.00	0.00	0.00
	C1084	17-Jun-05	0.77	0	0	0	0	0.00	0.00	0.00	0.00
	C1085	17-Jun-05	0.78	0	0	0	0	0.00	0.00	0.00	0.00
	C1086	17-Jun-05	0.75	0	0	1	1	0.00	0.00	1.33	1.33
	C1087	20-Jun-05	0.32	0	0	0	0	0.00	0.00	0.00	0.00
	C1089	20-Jun-05	0.39	0	0	2	2	0.00	0.00	5.11	5.11
	C774	20-Jun-05	0.33	0	0	1	1	0.00	0.00	2.99	2.99
	C776	20-Jun-05	0.53	0	0	0	0	0.00	0.00	0.00	0.00
	C784	20-Jun-05	0.64	0	0	0	0	0.00	0.00	0.00	0.00
	C786	20-Jun-05	0.75	0	0	1	1	0.00	0.00	1.34	1.34
	C797	17-Jun-05	0.75	0	0	5	5	0.00	0.00	6.64	6.64
	C808	17-Jun-05	0.75	0	0	14	14	0.00	0.00	18.59	18.59
	S165	17-Jun-05	0.54	0	0	0	0	0.00	0.00	0.00	0.00
	S166	17-Jun-05	0.79	0	0	0	0	0.00	0.00	0.00	0.00
	S255	17-Jun-05	1.01	0	0	0	0	0.00	0.00	0.00	0.00
	S258	17-Jun-05	1.17	0	0	0	0	0.00	0.00	0.00	0.00
	S262	20-Jun-05	0.96	0	0	1	1	0.00	0.00	1.04	1.04
	S290	20-Jun-05	1.48	0	0	0	0	0.00	0.00	0.00	0.00
	S294	30-Jun-05	0.70	0	0	0	0	0.00	0.00	0.00	0.00
Outer Bay	C747	16-Jun-05	0.43	0	0	2	2	0.00	0.00	4.62	4.62
	C748	16-Jun-05	0.76	0	0	3	3	0.00	0.00	3.96	3.96
	C749	16-Jun-05	0.75	0	0	4	4	0.00	0.00	5.32	5.32
	C751	16-Jun-05	0.52	0	0	5	5	0.00	0.00	9.59	9.59
	C756	18-Jun-05	0.67	0	0	4	4	0.00	0.00	5.96	5.96
	C757	18-Jun-05	0.51	0	0	2	2	0.00	0.00	3.93	3.93
	C759	18-Jun-05	0.72	0	0	7	7	0.00	0.00	9.78	9.78
	C765	18-Jun-05	0.46	0	0	10	10	0.00	0.00	21.56	21.56
	C766	19-Jun-05	0.46	0	0	1	1	0.00	0.00	2.19	2.19
	P750	16-Jun-05	0.76	0	0	4	4	0.00	0.00	5.25	5.25
	P752	16-Jun-05	0.75	0	0	0	0	0.00	0.00	0.00	0.00
	S128	16-Jun-05	0.23	0	0	0	0	0.00	0.00	0.00	0.00
	S129	16-Jun-05	0.98	0	0	0	0	0.00	0.00	0.00	0.00
	S137	18-Jun-05	0.82	0	0	4	4	0.00	0.00	4.87	4.87
	S139	19-Jun-05	0.63	0	0	0	0	0.00	0.00	0.00	0.00
	S141	19-Jun-05	0.71	0	0	0	0	0.00	0.00	0.00	0.00
	S142	19-Jun-05	0.34	0	0	0	0	0.00	0.00	0.00	0.00
	S144	18-Jun-05	1.06	0	0	4	4	0.00	0.00	3.79	3.79
	S149	18-Jun-05	0.66	0	0	3	3	0.00	0.00	4.55	4.55
	S151	18-Jun-05	0.17	0	0	0	0	0.00	0.00	0.00	0.00
	S156	17-Jun-05	0.71	0	0	0	0	0.00	0.00	0.00	0.00
	S157	17-Jun-05	0.46	0	0	0	0	0.00	0.00	0.00	0.00
	S160	17-Jun-05	0.78	0	0	0	0	0.00	0.00	0.00	0.00
	S265	18-Jun-05	1.12	0	0	0	0	0.00	0.00	0.00	0.00
	S266	19-Jun-05	0.70	0	0	0	0	0.00	0.00	0.00	0.00
	S267	19-Jun-05	0.92	0	0	0	0	0.00	0.00	0.00	0.00
	S291	18-Jun-05	1.34	0	0	0	0	0.00	0.00	0.00	0.00

Appendix C-1. Murrelet numbers and densities during Kachemak Bay surveys in June of 2006.

June 2006				**No. of observed murrelets**				**Murrelet Density** (birds/km^2)			
Transect Location	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	C1083	19-Jun-06	0.83	0	0	0	0	0.00	0.00	0.00	0.00
	C1084	19-Jun-06	0.66	0	0	0	0	0.00	0.00	0.00	0.00
	C1085	19-Jun-06	0.72	2	0	31	33	2.78	0.00	43.06	45.83
	C1086	20-Jun-06	0.65	0	0	19	19	0.00	0.00	29.23	29.23
	C1087	20-Jun-06	0.42	0	0	0	0	0.00	0.00	0.00	0.00
	C1089	20-Jun-06	0.37	0	0	5	5	0.00	0.00	13.51	13.51
	C774	19-Jun-06	0.48	2	0	1	3	4.17	0.00	2.08	6.25
	C776	17-Jun-06	0.50	0	0	0	0	0.00	0.00	0.00	0.00
	C784	17-Jun-06	0.65	0	0	0	0	0.00	0.00	0.00	0.00
	C786	17-Jun-06	0.81	0	0	2	2	0.00	0.00	2.47	2.47
	C797	19-Jun-06	0.82	0	2	13	15	0.00	2.44	15.85	18.29
	C808	20-Jun-06	0.8	0	4	14	18	0.00	5.00	17.50	22.50
	S165	20-Jun-06	0.28	0	0	0	0	0.00	0.00	0.00	0.00
	S166	20-Jun-06	0.82	0	0	0	0	0.00	0.00	0.00	0.00
	S255	20-Jun-06	1.02	0	0	2	2	0.00	0.00	1.96	1.96
	S258	29-Jun-06	1.17	0	0	0	0	0.00	0.00	0.00	0.00
	S262	17-Jun-06	0.79	0	0	0	0	0.00	0.00	0.00	0.00
	S290	29-Jun-06	1.45	0	0	0	0	0.00	0.00	0.00	0.00
	S294	not surveyed									
Outer Bay	C747	18-Jun-06	0.39	0	0	3	3	0.00	0.00	7.69	7.69
	C748	19-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	C749	18-Jun-06	0.75	0	0	2	2	0.00	0.00	2.67	2.67
	C751	18-Jun-06	0.48	0	0	0	0	0.00	0.00	0.00	0.00
	C756	17-Jun-06	0.77	0	0	2	2	0.00	0.00	2.60	2.60
	C757	19-Jun-06	0.52	1	0	11	12	1.92	0.00	21.15	23.08
	C759	17-Jun-06	0.66	0	0	12	12	0.00	0.00	18.18	18.18
	C765	17-Jun-06	0.47	2	0	25	27	4.26	0.00	53.19	57.45
	C766	20-Jun-06	0.51	0	0	0	0	0.00	0.00	0.00	0.00
	P750	18-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	P752	18-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	S128	18-Jun-06	0.21	0	0	0	0	0.00	0.00	0.00	0.00
	S129	18-Jun-06	1.13	0	0	0	0	0.00	0.00	0.00	0.00
	S137	17-Jun-06	0.91	0	0	0	0	0.00	0.00	0.00	0.00
	S139	20-Jun-06	0.72	0	0	0	0	0.00	0.00	0.00	0.00
	S141	20-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	S142	20-Jun-06	0.31	0	0	0	0	0.00	0.00	0.00	0.00
	S144	19-Jun-06	1.17	0	0	4	4	0.00	0.00	3.42	3.42
	S149	17-Jun-06	0.73	0	0	0	0	0.00	0.00	0.00	0.00
	S151	18-Jun-06	0.42	0	0	0	0	0.00	0.00	0.00	0.00
	S156	18-Jun-06	0.82	0	0	0	0	0.00	0.00	0.00	0.00
	S157	18-Jun-06	0.54	0	0	0	0	0.00	0.00	0.00	0.00
	S160	18-Jun-06	0.84	0	0	0	0	0.00	0.00	0.00	0.00
	S265	18-Jun-06	0.84	0	0	0	0	0.00	0.00	0.00	0.00
	S266	20-Jun-06	0.85	0	0	0	0	0.00	0.00	0.00	0.00
	S267	20-Jun-06	0.90	0	0	0	0	0.00	0.00	0.00	0.00
	S291	19-Jun-06	1.32	0	0	0	0	0.00	0.00	0.00	0.00

July 2005				No. of observed murrelets				Murrelet Density (birds/km²)			
Region	Transect	Date	Area (km²)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	23-Jul-05	0.64	1	18	34	53	1.56	28.13	53.13	82.81
	K2	21-Jul-05	2.24	10	53	73	136	4.46	23.66	32.59	60.71
	K3	21-Jul-05	2.27	15	15	80	110	6.61	6.61	35.24	48.46
	K4	21-Jul-05	2.15	1	0	5	6	0.47	0.00	2.33	2.79
	K5	21-Jul-05	2.21	0	0	2	2	0.00	0.00	0.90	0.90
	K6	18-Jul-05	2.76	2	0	18	20	0.72	0.00	6.52	7.25
Outer Bay	K7	19-Jul-05	2.42	4	0	27	31	1.65	0.00	11.16	12.81
	K8	19-Jul-05	3.53	2	0	31	33	0.57	0.00	8.78	9.35
	K9	19-Jul-05	3.71	1	0	21	22	0.27	0.00	5.66	5.93
	K10	20-Jul-05	4.00	8	1	96	105	2.00	0.25	24.00	26.25
	K11	20-Jul-05	5.82	18	5	110	133	3.09	0.86	18.90	22.85
	K12	22-Jul-05	5.89	23	1	61	85	3.90	0.17	10.36	14.43
			37.64	85	93	558	736	2.26	2.47	14.82	19.55

July 2006				No. of observed murrelets				Murrelet Density (birds/km²)			
Region	Transect	Date	Area (km²)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	20-Jul-06	1.11	3	7	4	14	2.7	6.3	3.6	12.6
	K2	20-Jul-06	2.16	9	79	24	112	4.2	36.6	11.1	51.9
	K3	20-Jul-06	2.65	9	12	86	107	3.4	4.5	32.4	40.3
	K4	18-Jul-06	2.32	0	0	2	2	0.0	0.0	0.9	0.9
	K5	18-Jul-06	2.38	1	0	6	7	0.4	0.0	2.5	2.9
	K6	18-Jul-06	2.84	0	2	2	4	0.0	0.7	0.7	1.4
Outer Bay	K7	19-Jul-06	3.09	0	0	22	22	0.0	0.0	7.1	7.1
	K8	19-Jul-06	3.47	1	0	27	28	0.3	0.0	7.8	8.1
	K9	19-Jul-06	3.70	2	0	11	13	0.5	0.0	3.0	3.5
	K10	20-Jul-06	3.90	5	18	18	41	1.3	4.6	4.6	10.5
	K11	21-Jul-06	5.81	5	15	152	172	0.9	2.6	26.1	29.6
	K12	21-Jul-06	5.93	5	26	198	229	0.8	4.4	33.4	38.6
			39.37	40	159	552	751	1.02	4.04	14.02	19.08

Appendix C-2. Murrelet numbers and densities during Kachemak Bay surveys in July of 2005-2007.

Appendix C-2 - continued. Murrelet numbers and densities during Kachemak Bay surveys in July of 2005 - 2007.

July 2007				**No. of observed murrelets**				**Murrelet Density (birds/km^2)**			
Region	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	25-Jul-07	1.08	0	0	2	2	0.00	0.00	1.86	1.86
	K2	22-Jul-07	2.00	18	42	45	105	9.00	21.00	22.50	52.49
	K3	22-Jul-07	2.47	6	5	44	55	2.43	2.03	17.85	22.31
	K4	22-Jul-07	2.46	1	2	6	9	0.41	0.81	2.44	3.66
	K5	22-Jul-07	2.35	2	0	1	3	0.85	0.00	0.43	1.28
	K6	22-Jul-07	2.72	0	0	8	8	0.00	0.00	2.94	2.94
Outer Bay	K7	24-Jul-07	2.83	4	1	114	119	1.41	0.35	40.22	41.98
	K8	24-Jul-07	3.55	0	0	188	188	0.00	0.00	52.92	52.92
	K9	24-Jul-07	3.69	3	0	15	18	0.81	0.00	4.06	4.87
	K10	23-Jul-07	3.77	1	0	6	7	0.27	0.00	1.59	1.86
	K11	23-Jul-07	5.72	3	1	23	27	0.52	0.17	4.02	4.72
	K12	23-Jul-07	5.95	9	3	17	29	1.51	0.50	2.86	4.87
			38.59	47	54	469	570	1.22	1.40	12.15	14.77

August 2004						No. of observed murrelets				Murrelet Density (birds/km^2)			
Region	Transect Group	Date	No. Trans	Transect	Total Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	Inner South Shore	8-Aug	3	XYZ	8.12	61	41	373	475	7.51	5.05	45.94	58.50
		16-Aug	3	XYZ	8.23	182	16	440	638	22.11	1.94	53.46	77.52
		23-Aug	3	XYZ	8.19	33	9	266	308	4.03	1.10	32.48	37.61
		3-Aug	1	8801	1.47	1	1	18	20	0.68	0.68	12.24	13.61
		5-Aug	4	8801-8804	4.11	8	14	196	218	1.95	3.41	47.69	53.04
		10-Aug	4	8801-8804	4.23	17	24	150	191	4.02	5.67	35.46	45.15
		14-Aug	4	8801-8804	4.21	22	18	233	273	5.23	4.28	55.34	64.85
		6-Aug	2	6 & 14	5.2	3	7	155	165	0.58	1.35	29.81	31.73
		11-Aug	2	6 & 14	5.56	6	3	98	107	1.08	0.54	17.63	19.24
		15-Aug	2	6 & 14	5.27	4	3	132	139	0.76	0.57	25.05	26.38
	Inner Zigzag	7-Aug	1	5	13.06	47	21	260	328	3.60	1.61	19.91	25.11
		21-Aug	1	5	12.33	9	9	266	284	0.73	0.73	21.57	23.03
Outer Bay	Eldredge Passage	4-Aug	5	8805-8809	3.81	5	0	254	259	1.31	0.00	66.67	67.98
		9-Aug	5	8805-8809	3.82	13	3	103	119	3.40	0.79	26.96	31.15
		12-Aug	5	8805-8809	3.98	5	3	41	49	1.26	0.75	10.30	12.31
	Outer South Shore	4-Aug	4	7-9, 10A	8.99	1	0	225	226	0.11	0.00	25.03	25.14
		9-Aug	4	7-9, 10A	10.47	9	9	189	207	0.86	0.86	18.05	19.77
		12-Aug	4	7-9, 10A	10.84	5	6	137	148	0.46	0.55	12.64	13.65
		22-Aug	3	7, 9, 10A	8.09	10	0	50	60	1.24	0.00	6.18	7.42
	Outer Zigzag	6-Aug	1	10	6.24	15	0	97	112	2.40	0.00	15.54	17.95
		17-Aug	1	10	6.83	2	0	64	66	0.29	0.00	9.37	9.66
	Outer North Shore	20-Aug	1	3	5.3	6	0	15	21	1.13	0.00	2.83	3.96
		20-Aug	1	2	1.94	3	3	15	21	1.55	1.55	7.73	10.82
Total numbers, average densities					150.29	467	190	3777	4434	3.11	1.26	25.13	29.50

Appendix C-3. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

Append. C-3 continued. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

August 2005						**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Region	**Transect Group**	**Date**	**No. Trans**	**Transect**	**Total Area (km²)**	**Unid.**	**Kittliz's**	**Marbled**	**Total Murrelets**	**Unid**	**Kittliz's**	**Marbled**	**Total Murrelets**
Inner Bay	Inner South Shore	9-Aug	3	XYZ	8.13	46	53	330	429	5.66	6.52	40.59	52.77
		16-Aug	3	XYZ	8.03	21	51	237	309	2.62	6.35	29.51	38.48
		4-Aug	4	8801-8804	4.21	13	22	221	256	3.09	5.23	52.49	60.81
		15-Aug	4	8801-8804	4.13	17	24	84	125	4.12	5.81	20.34	30.27
		22-Aug	4	8801-8804	4.24	22	10	107	139	5.19	2.36	25.24	32.78
		3-Aug	2	6 & 14	5.32	8	4	239	251	1.50	0.75	44.92	47.18
		10-Aug	2	6 & 14	5.45	3	2	69	74	0.55	0.37	12.66	13.58
		20-Aug	2	6 & 14	5.34	3	1	41	45	0.56	0.19	7.68	8.43
	Inner Zigzag	8-Aug	1	5	12.72	10	2	136	148	0.79	0.16	10.69	11.64
Outer Bay	Eldredge Passage	5-Aug	5	8805-8809	3.7	0	0	11	11	0.00	0.00	2.97	2.97
		14-Aug	5	8805-8809	3.75	3	0	35	38	0.80	0.00	9.33	10.13
	Outer South Shore	3-Aug	4	7-9, 10A	10.87	4	0	85	89	0.37	0.00	7.82	8.19
		10-Aug	4	7-9, 10A	11.11	2	2	62	66	0.18	0.18	5.58	5.94
		18-Aug	3	7, 9, 10A	7.93	8	0	93	101	1.01	0.00	11.73	12.74
		22-Aug	2	7, 9	4.89	0	0	12	12	0.00	0.00	2.45	2.45
	Outer Zigzag	6-Aug	1	10	6.06	1	0	22	23	0.17	0.00	3.63	3.80
		10-Aug	1	10	6.13	1	0	42	43	0.16	0.00	6.85	7.01
	Outer North Shore	7-Aug	1	3	5.01	3	0	2	5	0.60	0.00	0.40	1.00
		17-Aug	1	3	5.4	7	1	39	47	1.30	0.19	7.22	8.70
		7-Aug	1	2	1.74	5	0	35	40	2.87	0.00	20.11	22.99
		17-Aug	1	2	1.7	2	0	38	40	1.18	0.00	22.35	23.53
Total numbers, average densities					125.86	179	172	1940	2291	1.42	1.37	15.41	18.20

Append. C-3 continued. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

August 2006						**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Region	**Transect Group**	**Date**	**No. Trans**	**Transect**	**Total Area (km²)**	**Unid.**	**Kittliz's**	**Marbled**	**Total Murrelets**	**Unid**	**Kittliz's**	**Marbled**	**Total Murrelets**
Inner Bay	Inner South Shore	9-Aug	3	XYZ	8.13	46	53	330	429	5.66	6.52	40.59	52.77
		16-Aug	3	XYZ	8.03	21	51	237	309	2.62	6.35	29.51	38.48
		4-Aug	4	8801-8804	4.21	13	22	221	256	3.09	5.23	52.49	60.81
		15-Aug	4	8801-8804	4.13	17	24	84	125	4.12	5.81	20.34	30.27
		22-Aug	4	8801-8804	4.24	22	10	107	139	5.19	2.36	25.24	32.78
		3-Aug	2	6 & 14	5.32	8	4	239	251	1.50	0.75	44.92	47.18
		10-Aug	2	6 & 14	5.45	3	2	69	74	0.55	0.37	12.66	13.58
		20-Aug	2	6 & 14	5.34	3	1	41	45	0.56	0.19	7.68	8.43
	Inner Zigzag	8-Aug	1	5	12.72	10	2	136	148	0.79	0.16	10.69	11.64
Outer Bay	Eldredge Passage	5-Aug	5	8805-8809	3.7	0	0	11	11	0.00	0.00	2.97	2.97
		14-Aug	5	8805-8809	3.75	3	0	35	38	0.80	0.00	9.33	10.13
	Outer South Shore	3-Aug	4	7-9, 10A	10.87	4	0	85	89	0.37	0.00	7.82	8.19
		10-Aug	4	7-9, 10A	11.11	2	2	62	66	0.18	0.18	5.58	5.94
		18-Aug	3	7, 9, 10A	7.93	8	0	93	101	1.01	0.00	11.73	12.74
		22-Aug	2	7, 9	4.89	0	0	12	12	0.00	0.00	2.45	2.45
	Outer Zigzag	6-Aug	1	10	6.06	1	0	22	23	0.17	0.00	3.63	3.80
		10-Aug	1	10	6.13	1	0	42	43	0.16	0.00	6.85	7.01
	Outer North Shore	7-Aug	1	3	5.01	3	0	2	5	0.60	0.00	0.40	1.00
		17-Aug	1	3	5.4	7	1	39	47	1.30	0.19	7.22	8.70
		7-Aug	1	2	1.74	5	0	35	40	2.87	0.00	20.11	22.99
		17-Aug	1	2	1.7	2	0	38	40	1.18	0.00	22.35	23.53
Total numbers, average densities					125.86	179	172	1940	2291	1.42	1.37	15.41	18.20
		08/19/06	1	2	0.53	0	0	6	6	0.00	0.00	11.32	11.32
Total numbers, average densities					252.25	358	344	3886	4588	1.42	1.36	15.41	18.19

Appendix C-3 - continued. Murrelet numbers and densities during Kachemak Bay surveys in August of 2004 - 2007.

August 2007						**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Region	**Transect Group**	**Date**	**No. Trans**	**Transect**	**Total Area (km²)**	**Unid.**	**Kittliz's**	**Marbled**	**Total Murrelets**	**Unid**	**Kittliz's**	**Marbled**	**Total Murrelets**
Inner Bay	Inner South Shore	10-Aug	3	XYZ	7.95	24	98	342	464	3.02	12.33	43.02	58.36
		13-Aug	3	XYZ	8.12	47	90	336	473	5.79	11.08	41.38	58.25
		16-Aug	3	XYZ	7.84	10	60	263	333	1.28	7.65	33.55	42.47
		8-Aug	4	8801-8804	4.2	11	59	129	199	2.62	14.05	30.71	47.38
Outer Bay	Outer South Shore	9-Aug	4	7-9, 10A	10.54	8	0	68	76	0.76	0.00	6.45	7.21
		12-Aug	4	7-9, 10A	10.74	2	3	87	92	0.19	0.28	8.10	8.57
		15-Aug	4	7-9, 10A	10.28	2	1	164	167	0.19	0.10	15.95	16.25
Total numbers, average densities					59.67	104	311	1389	1804	1.74	5.21	23.28	30.23

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay of 2004. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2004				**Counts**						**Densities**			
Region	**Transect Set**	**Date**	**Transects**	**Kittlitz's**			**Marbled**			**Kittlitz's**		**Marbled**	
				Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	8-Aug	XYZ	38	3		371	2		0.37	0.00	0.25	0.00
		16-Aug	XYZ	13	3		434	6		0.36	0.00	0.73	0.00
		23-Aug	XYZ	9			260	5	1	0.00	0.00	0.61	0.12
		3-Aug	8801	1			18				0.00	0.00	0.00
		5-Aug	8801-8804	13	1		194		2	0.24	0.00	0.00	0.49
		10-Aug	8801-8804	24			150				0.00	0.00	0.00
		14-Aug	8801-8804	17	1		232	0	1	0.24	0.00	0.00	0.24
		6-Aug	6 & 14	7			154	1		0.00	0.00	0.19	0.00
		11-Aug	6 & 14	3			96	2		0.00	0.00	0.36	0.00
		15-Aug	6 & 14	3			127	5		0.00	0.00	0.95	0.00
	Inner Zigzag	7-Aug	5	20	1		254	1	5	0.08	0.00	0.08	0.38
		21-Aug	5	7	1	1	260	5	1	0.08	0.08	0.41	0.08
Outer Bay	Eldredge Passage	4-Aug	8805 - 8809				254			0.00	0.00	0.00	0.00
		9-Aug	8805 - 8809	3			99	3	1	0.00	0.00	0.79	0.26
		12-Aug	8805 - 8809	3			28	12	1	0.00	0.00	3.02	0.25
	Outer South Shore	4, 6-Aug	7-9, 10A				219	4	2	0.00	0.00	0.45	0.22
		9, 11-Aug	7-9, 10A	7	2		176	13		0.19	0.00	1.24	0.00
		12, 15-Aug	7-9, 10A	2	4		111	26		0.37	0.00	2.40	0.00
		22-Aug	7, 9, 10A				40	10		0.00	0.00	1.24	0.00
	Outer Zigzag	6-Aug	10				93	4		0.00	0.00	0.64	0.00
		17-Aug	10				42	22		0.00	0.00	3.22	0.00
	Outer N.Shore	20-Aug	3				15			0.00	0.00	0.00	0.00
		20-Aug	2	3			15			0.00	0.00	0.00	0.00

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2005. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

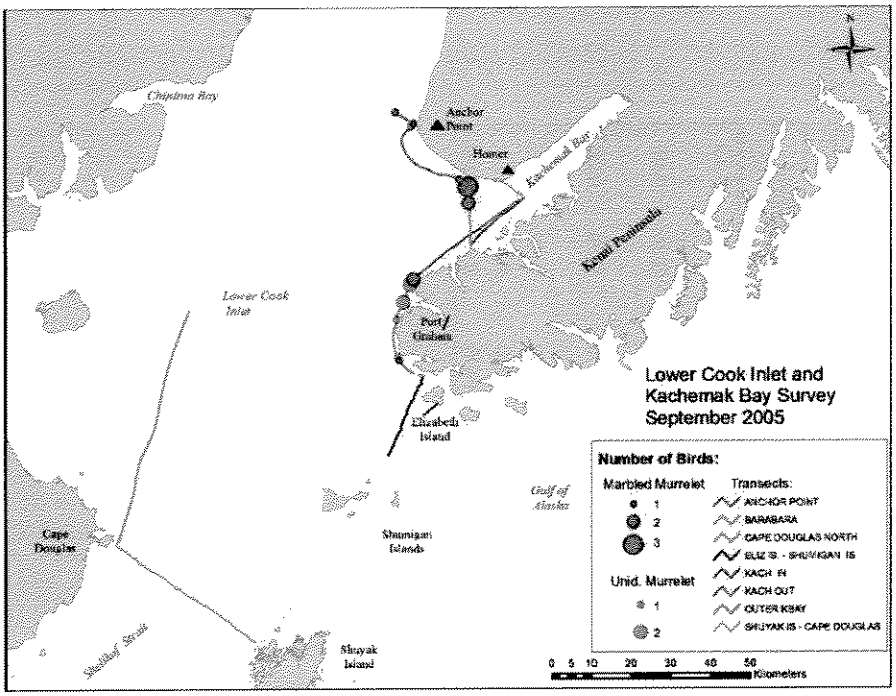
August 2005				Counts						Densities			
				Kittlitz's			Marbled			Kittlitz's		Marbled	
Region	Transect Set	Date	Transects	Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	9-Aug	XYZ	53			328	2	0	0.00	0.00	0.25	0.00
		16-Aug	XYZ	49	2		237			0.25	0.00	0.00	0.00
		4-Aug	8801-8804	22			217	4		0.00	0.00	0.95	0.00
		15-Aug	8801-8804	24			84			0.00	0.00	0.00	0.00
		22-Aug	8801-8804	10			105	2		0.00	0.00	0.47	0.00
		3-Aug	6 & 14	4			237	1	1	0.00	0.00	0.19	0.00
		10-Aug	6 & 14	2			69			0.00	0.00	0.00	0.00
		20-Aug	6 & 14	1			38	3		0.00	0.00	0.56	0.00
	Inner Zigzag	8-Aug	5	2			136			0.00	0.00	0.00	0.00
Outer Bay	Eldredge Passage	5-Aug	8805-8809				10	1		0.00	0.00	0.27	0.00
		14-Aug	8805-8809				33	2		0.00	0.00	0.53	0.00
	Outer South Shore	3-Aug	7-9, 10A				68	13	4	0.00	0.00	1.20	0.00
		10-Aug	7-9, 10A	1	1		47	15		0.09	0.00	1.35	0.00
		18-Aug	7, 9, 10A				73	20		0.00	0.00	2.52	0.00
		22-Aug	7, 9				8	4		0.00	0.00	0.82	0.00
	Outer Zigzag	6-Aug	10				18	4		0.00	0.00	0.66	0.00
		10-Aug	10				42			0.00	0.00	0.00	0.00
	Outer N.Shore	7-Aug	3				2			0.00	0.00	0.00	0.00
		17-Aug	3		1		38	1		0.19	0.00	0.19	0.00
		7-Aug	2				26	6	3	0.00	0.00	3.45	0.00
		17-Aug	2				38			0.00	0.00	0.00	0.00

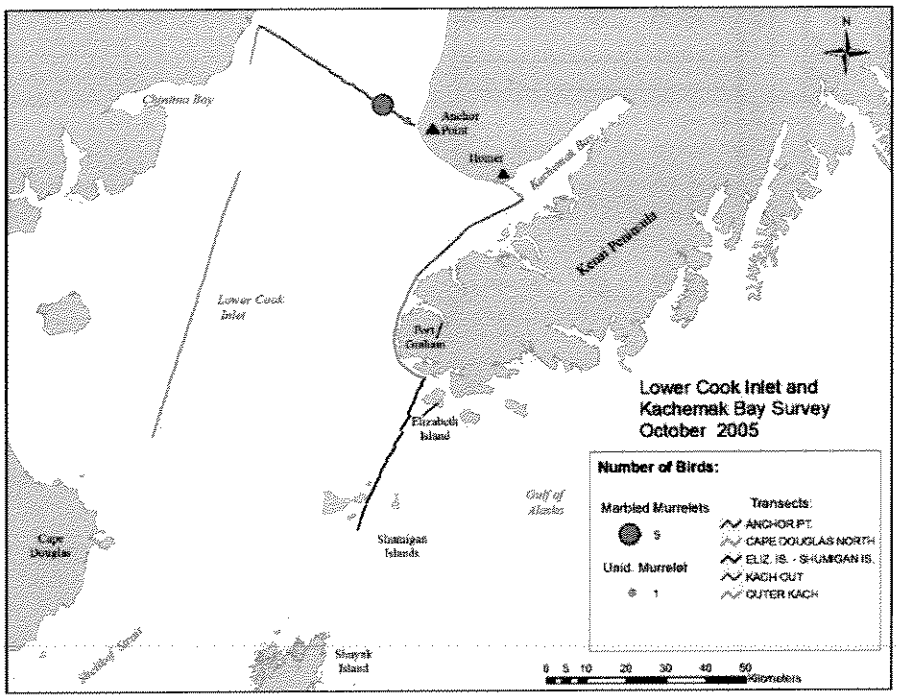
Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2006. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2006				**Counts**						**Densities**			
				Kittlitz's			**Marbled**			**Kittlitz's**		**Marbled**	
Region	**Transect Set**	**Date**	**Transects**	Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	6-Aug	XYZ	343	3	2	285	1		0.37	0.25	0.12	0.00
		12-Aug	XYZ	180	3	3	859	2		0.37	0.37	0.24	0.00
		21-Aug	XYZ	32		2	311	2		0.00	0.25	0.25	0.00
		1-Aug	8801-8804	158			82			0.00	0.00	0.00	0.00
		8-Aug	8801-8804	219			114	2		0.00	0.00	0.47	0.00
		15-Aug	8801-8804	26	7	1	255	1		1.63	0.23	0.23	0.00
		3-Aug	6 & 14	5			126			0.00	0.00	0.00	0.00
		10-Aug	6 & 14	1			71	1		0.00	0.00	0.18	0.00
		20-Aug	6 & 14	1			100	3		0.00	0.00	0.58	0.00
Outer Bay	Eldredge Passage	2-Aug	8805-8809	0			182	3		0.00	0.00	0.79	0.00
		9-Aug	8805-8809	0			25	1		0.00	0.00	0.26	0.00
		17-Aug	8805-8809	0			23	9	1	0.00	0.00	2.29	0.25
		23-Aug	8805-8809	0			23	1	2	0.00	0.00	0.26	0.52
	South outer shore	2-Aug	7-9, 10A	0	1		259	1		0.10	0.00	0.10	0.00
		9-Aug	7-9, 10A	1			91	3		0.00	0.00	0.29	0.00
		17-Aug	7-9, 10A	2			69	22	2	0.00	0.00	2.15	0.20
		23-Aug	10A	0			7	12		0.00	0.00	4.74	0.00
		5-Aug	10	0			37	1		0.00	0.00	0.17	0.00
		15-Aug	10	0			11	1		0.00	0.00	0.17	0.00
	N.Outer shore	7-Aug	3	0			14			0.00	0.00	0.00	0.00
		19-Aug	3	0			5	1		0.00	0.00	0.20	0.00
		7-Aug	2	0			2			0.00	0.00	0.00	0.00
		19-Aug	2	0			6			0.00	0.00	0.00	0.00

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2007. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2007				**Counts**						**Densities**			
Region	**Transect Set**	**Date**	**Transects**	**Kittlitz's**			**Marbled**			**Kittlitz's**		**Marbled**	
				Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	10-Aug	XYZ	97		1	339	2	1	0.00	0.13	0.25	0.13
		13-Aug	XYZ	88	1	1	335	1		0.12	0.12	0.12	0.12
		16-Aug	XYZ	60			261	2		0.00	0.00	0.26	0.00
		8-Aug	8801-8804	59			128	1		0.00	0.00	0.24	0.00
Outer Bay	Outer South Shore	9-Aug	7-9, 10A	0			61	6	1	0.00	0.00	0.57	0.00
		12-Aug	7-9, 10A	1	2		86	1		0.19	0.00	0.09	0.00
		15-Aug	7-9, 10A	1			160	4		0.00	0.00	0.39	0.00





Appendix D. Observations of marbled murrelets and unidentified *Brachyramphus* murrelets in outer Kachemak Bay and Cook Inlet during transits in the *F/V Columbia* in September and October of 2005.

Appendix E-1. Population estimates for all species observed in Kachemak Bay during June surveys of 1993, 2005, and 2006.

Taxon		June 1993		June 2005		June 2006	
		N	*95% CI*	*N*	*95% CI*	*N*	*95% CI*
Common Name	Latin name						
BIRDS							
Common Loon	*Gavia immer*	234	233	93	110	217	223
Northern Fulmar	*Fulmaris glacialis*	-	-	55	105	-	-
Short-tailed Shearwater	*Puffinus tenuirostris*	53	102	602	798	-	-
Sooty Shearwater	*Puffinus griseus*	158	223	47,568	45,641	990	1,224
Unidentified Shearwater	*Puffinus* sp.	-	-	3,832	7,164	521	703
Double-crested Cormorant	*Phalacrocorax auritus*	3	5	3	5	13	21
Pelagic Cormorant	*Phalacrocorax pelagicus*	248	243	370	345	146	209
Pelagic or Red-faced Cormorant	*Phalacrocorax pelagicus OR urile*	-	-	-	-	93	147
Common Eider	*Somateria mollissima*	63	100	64	106	-	-
Harlequin Duck	*Histrionicus histrionicus*	225	158	1,815	1,804	1,180	585
Long-tailed Duck	*Clangula hyemalis*	-	-	-	-	3	5
Surf Scoter	*Melanitta perspicillata*	516	713	57	68	598	1,014
Black Scoter	*Melanitta americana*	-	-	83	118	6	10
White-winged Scoter	*Melanitta fusca*	14	12	67	107	309	319
Unidentified Scoter	*Melanitta* sp.	-	-	87	114	313	604
Barrow's Goldeneye	*Bucephala islandica*	-	-	-	-	732	1,333
Unidentified Duck	Family Anatidae	-	-	-	-	10	12
Black Oystercatcher	*Haematopus bachmani*	-	-	3	5	10	12
Red-necked Phalarope	*Phalaropus lobatus*	-	-	109	212	-	-
Bald Eagle	*Haliaeetus leucocephalus*	135	39	266	179	152	110
Parasitic Jaeger	*Stercorarius parasiticus*	-	-	55	106	-	-
Unidentified Shorebird		-	-	3	5	52	102
Bonaparte's Gull	*Larus philadelphia*	161	258	113	148	-	-
Mew Gull	*Larus canus*	452	472	138	218	42	36
Herring Gull	*Larus argentatus*	-	-	41	38	55	100
Glaucous-winged Gull	*Larus glaucescens*	12,036	13,197	7,117	3,786	6,048	4,226
Sabine's Gull	*Xema sabini/Larus sabini*	-	-	-	-	3	5
Black-legged Kittiwake	*Rissa tridactyla*	21,943	12,449	12,925	4,804	9,656	3,550
Unidentified Gull	Family Laridae	-	-	102	152	13	12
Aleutian Tern	*Onychoprion aleuticus*	53	102	109	211	55	101

Appendix E-1, continued. Population estimates for all species observed in Kachemak Bay in June of 1993, 2005, and 2006.

Taxon		June 1993		June 2005		June 2006	
		N		*N*		*N*	
Common Name	Latin name						
BIRDS (Cont'd)							
Pigeon Guillemot	*Cepphus columba*	1,588	702	1,365	1,294	1,482	879
Kittlitz's Murrelet	*Brachyramphus brevirostris*	328	447	-	-	319	435
Marbled Murrelet	*Brachyramphus marmoratus*	984	1,336	3,651	1,823	7,312	4,376
Brachyramphus Murrelet (Unidentified)	*Brachyramphus* spp.	4,354	4,617	-	-	365	351
Brachyramphus Murrelet (Total)	*Brachyramphus* spp.	5,666	5,784	3,651	1,823	7,989	4,703
Ancient Murrelet	*Synthliboramphus antiquus*	-	-	55	105	-	-
Common Murre	*Uria aalge*	82,505	146,865	29,192	40,767	10,369	11,587
Unidentified Murre	*Uria* sp.	-	-	-	-	417	377
Horned Puffin	*Fratercula corniculata*	111	208	3	5	-	-
Tufted Puffin	*Fratercula cirrhata*	487	738	1,040	1,511	1,305	1,415
Northwestern Crow	*Corvus caurinus*	179	110	430	295	318	184
Tree Swallow	*Tachycineta bicolor*	-	-	3	5	-	-
MAMMALS							
Harbor Porpoise	*Phocoena phocoena*	-	-	3	5	10	11
Harbor Seal	*Phoca vitulina*	187	168	195	153	110	116
Sea Otter	*Enhydra lutris*	3,053	2,262	2,071	1,768	1,991	1,512

Appendix E-2. Population estimates for all species observed in Kachemak Bay during July surveys, 2005 – 2007.

Taxon	July 2005			July 2006			July 2007		
	birds/km²	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*
BIRDS									
Aleutian Tern	0.29	238	208	0.08	62	77	0.16	127	203
Ancient Murrelet	0.27	217	338	0.00	-	-	0.00	-	-
Arctic Tern	2.98	2,427	1,117	1.09	891	1,116	0.47	380	478
Bald Eagle	0.03	22	43	0.00	-	-	0.05	42	61
Black-legged Kittiwake	9.56	7,801	3,817	10.44	8,516	2,424	11.92	9,722	4,601
Brachyramphus *Murrelet (Unidentified)*	2.26	1,842	856	1.02	829	468	1.22	993	757
Brachyramphus *Murrelets (Total)*	19.55	15,949	6,811	19.08	15,561	8,112	14.77	12,047	8,840
Common Loon	0.03	22	41	0.05	41	81	0.18	148	138
Common Murre	13.04	10,640	9,678	6.81	5,553	3,362	23.19	18,916	12,161
Fork-tailed Storm Petrel	0.53	433	389	0.10	83	148	0.00	-	-
Glaucous-winged Gull	1.67	1,365	1,186	3.91	3,191	1,361	7.75	6,319	6,509
Harlequin Duck	0.13	108	207	0.00	-	-	0.00	-	-
Herring Gull	0.03	22	42	0.05	41	50	0.34	275	199
Hooded Merganser	0.00	-	-	0.00	-	-	0.00	-	-
Horned Puffin	0.29	238	245	0.00	-	-	0.05	42	52
Kittlitz's Murrelet	2.47	2,015	2,474	4.04	3,294	3,171	1.40	1,141	1,759
Leach's Storm Petrel	0.05	43	82	0.00	-	-	0.00	-	-
Long-tailed Jaeger	0.00	-	-	0.03	21	39	0.00	-	-
Marbled Murrelet	14.82	12,092	4,506	14.02	11,437	6,895	12.15	9,912	8,201
Mew Gull	0.16	130	117	0.10	83	121	0.03	21	41
Northern Fulmar	0.03	22	41	0.00	-	-	0.00	-	-
Northwestern Crow	0.21	173	309	0.00	-	-	0.03	21	38
Pacific Loon	0.08	65	83	0.13	104	105	0.08	63	83
Pelagic Cormorant	0.21	173	259	0.00	-	-	0.03	21	41
Pelagic or Red-faced Cormorant	0.03	22	43	0.00	-	-	0.00	-	-
Pigeon Guillemot	1.49	1,213	1,254	1.17	953	892	1.43	1,162	464
Red-faced Cormorant	0.16	130	254	0.00	-	-	0.00	-	-
Red-necked Grebe	0.03	22	39	0.00	-	-	0.00	-	-
Red-necked Phalarope	2.44	1,994	1,977	1.50	1,222	1,068	1.35	1,099	1,304

Taxon	July 2005			July 2006			July 2007		
	birds/km²	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*
BIRDS (cont'd)									
Sooty Shearwater	18.68	15,234	10,818	13.92	11,354	17,948	0.65	528	681
Surf Scoter	0.58	477	635	0.30	249	251	0.05	42	59
Thick-billed Murre	0.11	87	96	0.00	-	-	0.00	-	-
Tufted Puffin	0.24	195	261	0.18	145	244	0.26	211	166
White-winged Scoter	0.24	195	273	0.61	497	545	0.26	211	280
Unidentified Alcid	0.05	43	55	0.00	-	-	0.00	-	-
Unidentified Duck	0.05	43	58	0.00	-	-	0.00	-	-
Unidentified Gull	0.19	152	175	0.08	62	118	0.00	-	-
Unidentified Loon	0.03	22	38	0.00	-	-	0.26	211	431
Unidentified Murre	1.51	1,235	946	3.91	3,191	5,707	0.44	359	278
Unidentified Phalarope	0.35	282	492	0.00	-	-	0.00	-	-
Unidentified Puffin	0.05	43	77	0.00	-	-	0.00	-	-
Unidentified Scoter	0.00	-	-	0.08	62	123	0.03	21	42
Unidentified Shearwater	1.89	1,539	1,559	0.00	-	-	0.00	-	-
Unidentified Shorebird	0.32	260	462	0.10	83	169	0.00	-	-
Unidentified Storm-petrel	0.05	43	82	0.00	-	-	0.00	-	-
Unidentified Tern	0.50	412	313	0.05	41	45	0.31	254	436
MAMMALS									
Harbor Porpoise	0.00	-	-	0.03	21	41	0.00	-	-
Harbor Seal	0.08	65	98	0.23	186	223	0.08	63	71
Minke Whale	0.00	-	-	0.03	21	37	0.00	-	-
Sea Otter	2.87	2,340	833	3.99	3,253	2,382	3.32	2,705	959

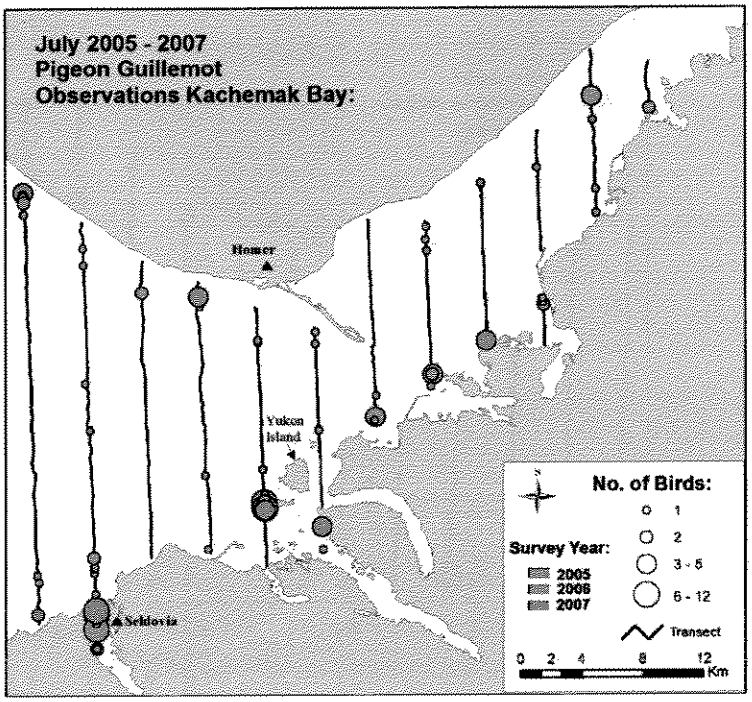
Appendix E-2 continued. Population estimates for all species observed during Kachemak Bay surveys in July, 2005 – 2007.

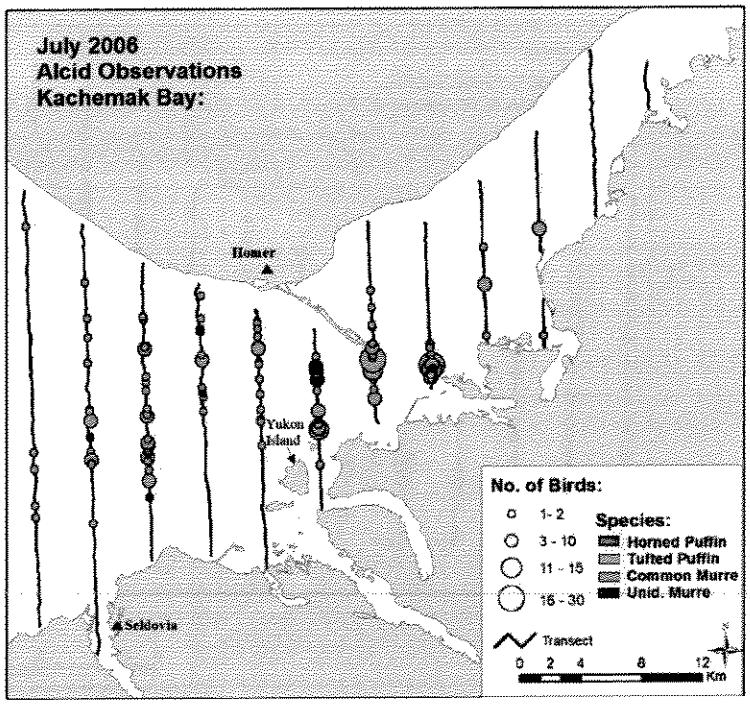
Appendix E-3. Densities of seabirds and marine mammals recorded during transits on the F/V Columbia, 4-5 September, 2005. Densities are given for different legs of the cruise, as shown in Appendix D-2. In September 253 km of transects were surveyed (38.1 km^2 with 150 m transect width).

September	Anchor Pt.	Barabara line	Cape Douglas North	Eliz. Is - Barren Is.	Into Kach	Out of Kach	Outer Kach	Shuyak Is.- Cape Douglas
Ancient Murrelet	3.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Black-legged Kittiwake	26.08	16.74	0.76	6.26	4.74	5.89	23.11	1.38
Brachyramphus Murrelet	0.20	0.80	0.00	0.00	0.00	0.00	1.40	0.00
Common Loon	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Common Murre	1.42	11.16	2.07	4.29	5.83	10.76	1.63	0.46
Dall's Porpoise	0.00	0.00	0.00	1.65	0.00	0.00	0.00	0.00
Fork-tailed Storm-petrel	0.00	0.00	0.65	0.00	0.36	0.00	0.00	0.00
Glaucous-winged Gull	0.81	0.00	0.11	0.99	0.36	1.22	1.40	1.84
Harbor Porpoise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
Harlequin Duck	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harbor Seal	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Herring Gull	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.15
Horned Puffin	5.46	0.00	0.00	0.66	0.00	0.00	0.70	0.46
Marbled Murrelet	0.61	3.59	0.00	0.00	0.00	0.00	0.70	0.00
Northern Fulmar	0.00	0.00	3.71	1.98	0.00	0.00	0.00	3.53
Pacific Loon	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pelagic Cormorant	0.81	3.19	0.00	0.00	0.00	0.20	0.00	0.00
Pigeon Guillemot	12.54	1.99	0.00	0.00	0.00	0.00	0.47	0.00
Red Phalarope	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00
Rhinoceros Auklet	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Red-necked Grebe	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00
Red-necked Phalarope	0.00	1.20	0.00	0.00	3.28	0.81	0.00	0.77
Sea Otter	2.83	0.80	0.00	0.33	0.00	0.41	0.00	0.15
Sooty Shearwater	4.85	0.40	0.22	0.66	0.00	0.00	0.93	1.23
Thick-billed Murre	0.20	0.40	0.22	0.00	0.00	0.20	0.00	0.00
Tufted Puffin	0.00	0.00	0.00	19.78	0.00	1.22	14.94	0.77
Unid. Alcid	0.00	0.00	0.00	0.66	0.36	0.00	0.00	0.31
Unid. Bird	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00
Unid. Gull	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Unid. Loon	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unid. Murre	0.00	0.00	0.33	1.98	0.00	0.00	0.00	0.00
Unid. Passerine	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unid. Phalarope	1.01	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Unid. Shearwater	5.66	0.00	0.55	1.65	0.00	2.03	0.93	0.61
White-winged Scoter	0.61	0.00	0.00	0.00	0.00	0.00	0.23	0.00

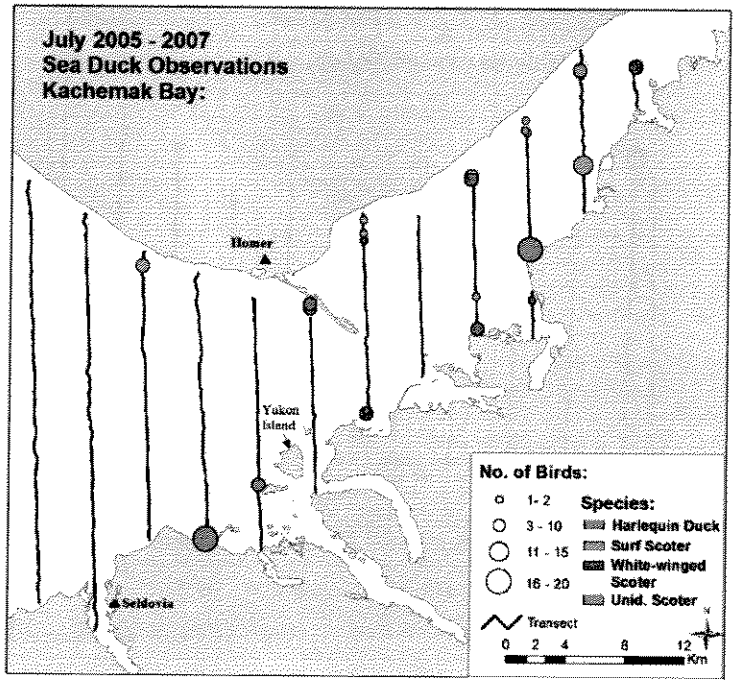
Appendix E-3, continued. Densities of seabirds and marine mammals recorded during transits onboard the F/V Columbia, 13-14 October 2005. Densities are given for different legs of the cruise, as shown in Appendix D-2. In October 228 km were surveyed (34.3 km^2 with 150 m transect width).

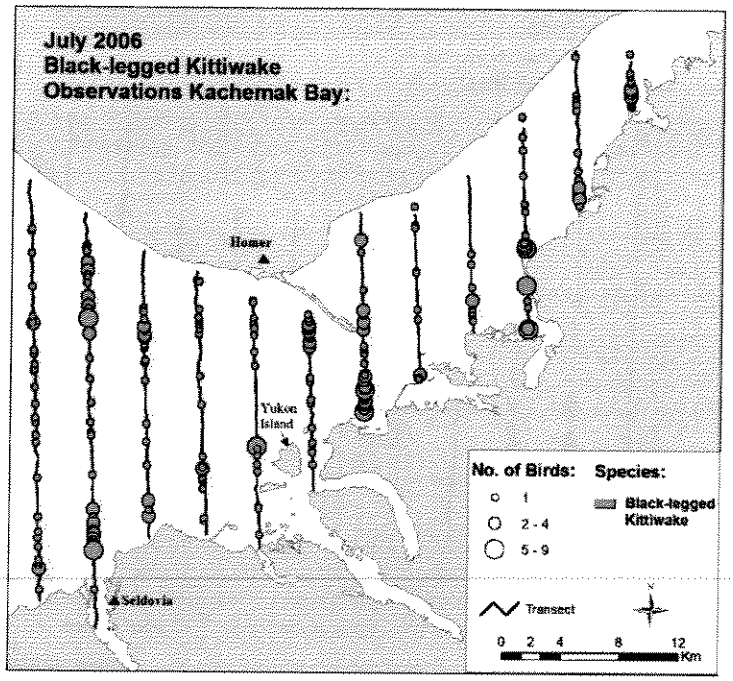
October	Anchor Pt.	Cape Douglas	Eliz. Is. - Barren Is.	Out of Kach	Outer Kach
Black-legged Kittiwake	2.80	0.00	1.01	0.40	1.99
Bonaparte's Gull	0.00	0.08	0.00	0.00	0.00
Brachyramphus Murrelet	0.15	0.00	0.00	0.00	0.00
Canada Goose	0.00	0.08	0.00	0.00	0.00
Common Eider	0.00	0.25	0.00	0.00	0.00
Common Murre	0.74	1.33	0.00	6.78	6.41
Glaucous-winged Gull	4.42	2.33	8.28	2.39	7.30
Herring Gull	0.15	0.17	0.00	0.20	0.44
Horned Puffin	0.00	0.25	0.00	0.00	0.44
Marbled Murrelet	0.74	0.00	0.00	0.00	0.00
Mew Gull	0.00	0.00	0.00	4.78	1.11
Northern Fulmar	1.91	0.00	0.00	0.00	0.00
Pelagic Cormorant	0.00	0.00	0.17	0.00	1.77
Pigeon Guillemot	0.15	0.00	0.00	0.20	0.00
Red-necked Grebe	0.00	0.00	0.00	0.00	0.22
Surf Scoter	0.00	0.00	0.00	0.20	0.00
Thick-billed Murre	0.00	0.08	0.00	0.00	0.22
Tufted Puffin	0.15	0.08	0.17	0.60	2.21
Unid. Alcid	0.00	0.17	0.00	0.40	0.44
Unid. Gull	0.15	0.00	0.00	0.20	0.00
Unid. Loon	0.29	0.00	0.00	0.00	0.22
Unid. Shorebird	0.00	0.17	0.00	0.00	0.00
White-winged Scoter	0.29	0.00	0.00	1.40	4.20



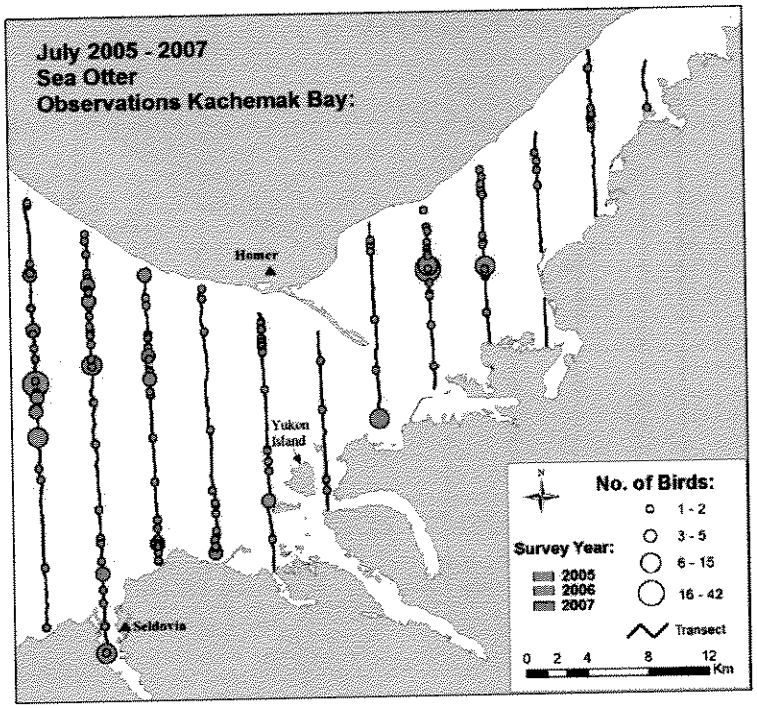


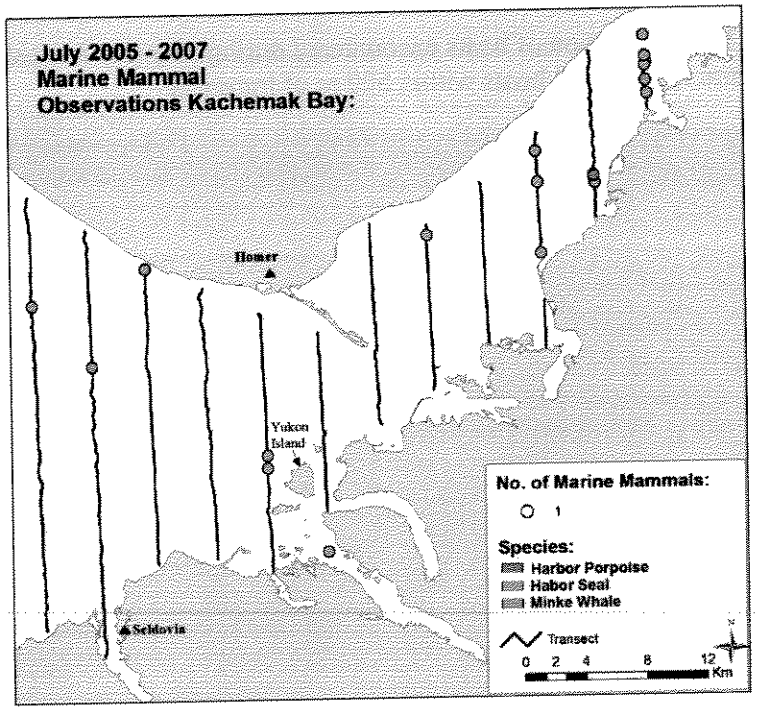
Appendix F. Distribution of pigeon guillemots (top) during July surveys of Kachemak Bay, 2005 - 2007. Distribution of other alcids (bottom) is shown for July 2006 only.



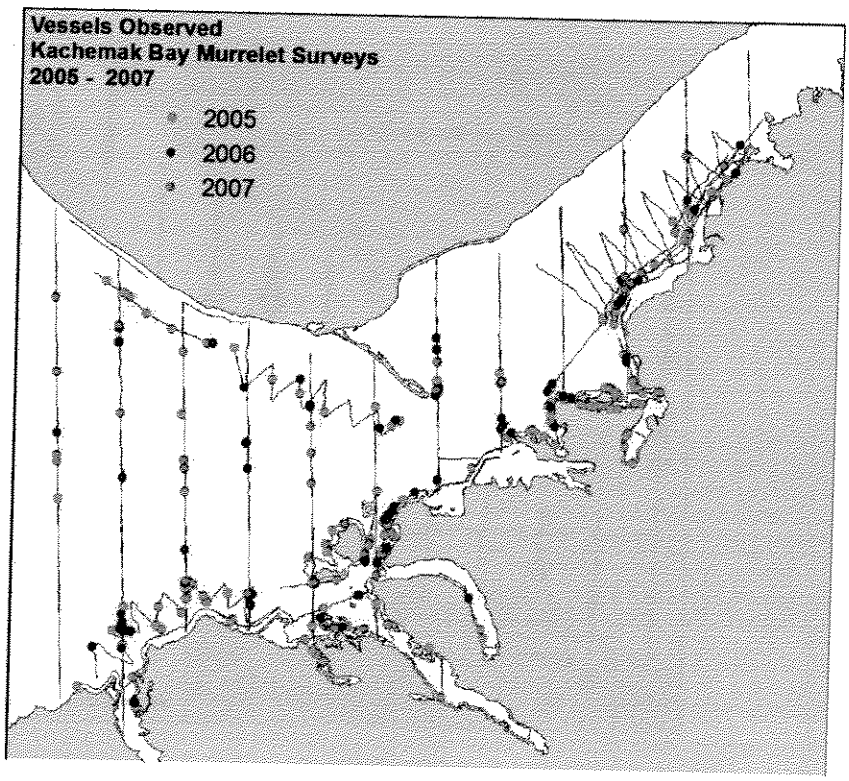


Appendix F. Distribution of sea ducks (top) recorded during July surveys of Kachemak Bay, 2005-2007, and black-legged kittiwakes (bottom) in July of 2006.





Appendix F. Distribution of sea otters (top) and other marine mammals (bottom) during July surveys of Kachemak Bay, 2005-2007.



Appendix F. Distribution of boats encountered during July and August surveys, 2005 – 2007. Figure includes all boats within 500 m of transects.

Location	Latitude	Longitude	CTD Station
June Casts			
Inner Bay	59 37.9	-151 20.1	5L
Inner Bay	59 39.5	-151 16	4L
Inner Bay	59 41.2	-151 12	3L
Inner Bay	59 43.1	-151 08	2L
Inner Bay	59 44.3	-151 05.7	1L
Outer Bay	59 32.1	-151 43.9	11L
Outer Bay	59 33.3	-151 40.2	10L
Outer Bay	59 33.7	-151 36	9L
Outer Bay	59 34	-151 32	8L
Outer Bay	59 34.9	-151 28	7L
Outer Bay	59 35.9	-151 24	6L
July Casts			
Inner Bay	59 44.2	-151 04	1A
Inner Bay	59 43	-151 08	2B
Inner Bay	59 41	-151 08	2C
Inner Bay	59 42	-151 12	3A
Inner Bay	59 39	-151 12	3B
Inner Bay	59 40.4	-151 16	4A
Inner Bay	59 39	-151 16	4B
Inner Bay	59 36	-151 16	4C
Inner Bay	59 39.2	-151 20	5A
Inner Bay	59 37	-151 20	5B
Inner Bay	59 35	-151 20.2	5C
Inner Bay	59 37	-151 24	6B
Inner Bay	59 33.6	-151 24	6C
Inner Bay	59 39	-151 16	4X
Inner Bay	59 40	-151 12	3-1
Inner Bay	59 41	-151 12	3-2
Inner Bay	59 42	-151 08	2-2
Inner Bay	59 43.9	-151 08	2-3
Outer Bay	59 36	-151 28	7A
Outer Bay	59 34	-151 28	7B
Outer Bay	59 32	-151 28	7C
Outer Bay	59 37	-151 36	9A
Outer Bay	59 34	-151 36	9B
Outer Bay	59 30	-151 36	9C
Outer Bay	59 38	-151 44	11A
Outer Bay	59 34	-151 44	11B
Outer Bay	59 29.1	-151 43.9	11C
Outer Bay	59 40.0	-151 48	12A
Outer Bay	59 37.0	-151 48	12B
Outer Bay	59 34.0	-151 48	12C
Outer Bay	59 30.0	-151 48	12D
Outer Bay	59 27.4	-151 48	12E

Appendix G. Location of CTD Casts in Kachemak Bay.

APPENDIX B

Power to Detect Trends in *Brachyramphus* Murrelet Populations in Southeast Alaska

Final Report
for the Alaska Department of Fish and Game

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INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small seabird that inhabits near-shore marine waters from central California to the Bering Sea of Alaska. Its distribution is closely tied to that of the Pacific Coast Temperate Rainforest, where it nests primarily on natural moss platforms in the canopy of old-growth trees. The loss of nesting habitat, especially in the southern portions of its range outside of Alaska, and increased mortality from anthropogenic factors such as oil spills and fishery by-catch, led to this species being listed as threatened in California, Oregon, Washington and British Columbia.

Southeast Alaska is an important population center for the species, supporting an estimated 65% of the global population. The original population estimate for Southeast Alaska is derived from a single region-wide survey conducted by the USFWS in the summer of 1994 (Agler et al. 1998; hereafter called the "Agler surveys"). Other agencies and individuals conducted surveys at various locations in the early 1990s for purposes of monitoring this species and detecting population trends (**Table 1**). Except for the Glacier Bay/Icy Strait area, however, these surveys have never been repeated and population trends for the region are poorly known. Results of recent analyses (Piatt et al. 2007) suggest that there has been a rapid and widespread decline in *Brachyramphus* murrelet populations throughout most of their range in British Columbia and Alaska. The evidence for major declines in abundance is strongest from Southeast Alaska and Prince William Sound owing to time-series data in both locations. In Southeast Alaska, there is good agreement with rates of *Brachyramphus* murrelet decline estimated from Icy Strait and Glacier Bay (-12.7 vs. -11.8 percent per year), and these declines are corroborated by comparison of Agler's survey with a region-wide survey conducted by Hodges et al. (Piatt et al., 2007) 4-7 years later than Agler, although questions remain about their comparability. Declines in Prince William Sound were less extreme, but still large at -6.7 percent per year. Numbers of *Brachyramphus* murrelets along the Malaspina Forelands, in Kachemak Bay, and at Adak Island were all negative, and slightly positive at Kenai Fjords.

A number of these historical surveys for seabirds at sea in SE Alaska, including those conducted by the U.S. Forest Service (USFS) but not analyzed by Piatt et al. (2007), could be repeated in order to better evaluate population trends at local or regional scales. However, it is not entirely obvious which methods of surveying would be best to replicate in the future. These surveys have differed markedly with respect to data collection protocol and sampling design, and they have never been contrasted for their power to detect trends. The purpose of this project was to collate and analyze existing historical murrelet survey data to determine which offers the most efficient method for detecting trends, and to make recommendations for conducting region-wide population and trend surveys in Southeast Alaska.

Analysis of datasets (Table 1) were performed to determine:

1. Power of each data set– what degree of change, assessed annually, can be detected with each data set. How do surveys measuring temporal variance (BC surveys; #9-12) compare to those measuring spatial variance (Alaska surveys; #1-8)? Similarly, what is the relative power of surveys conducted with random sampling (#1), opportunistic sampling (#2,7), or systematic

sampling (#5,8), surveys conducted from small skiffs (#1,2,3) versus larger, slower vessels (#4,7), transects conducted nearshore versus offshore (#1), in different geographic regions (North versus South, #2) or data collected using line transect protocols (#3)?

2. Sample size – given the above, what is the relationship between survey effort and power (specifically, degree of change that can be assessed annually)?

3. Superior method – given the above, what transect method is the most efficacious, providing the highest degree of certainty with the lowest input of survey effort?

4. Interannual sampling rate – given above; assuming a necessity for determining 50% changes over different times intervals (say 10, 15 or 20 years) and assuming that survey effort is limited by personnel and financial resources, which is the superior method for surveying murrelets: annual surveys or surveys every n years?

5. Survey design – given above, what is the most efficacious geographic design for surveys (selected from a continuum of a single survey, repeated within seasons, to multiple surveys, each conducted once annually). In other words, from the point of view of power to detect change, but also given that the population is dispersed widely over all of SE Alaska (ca. 30,000 square km), and that resources for monitoring in the future will only ever permit sampling the entire area infrequently (e.g., once every 10 years) or to sample a much smaller area annually (and perhaps repeatedly within season), but not both, which is the superior strategy for monitoring populations? Should we move towards a i) spatially comprehensive survey, or, ii) a (random or core?) selection of several sub-areas to survey, perhaps repeatedly within year?

Survey and Data Descriptions

Following is a brief description of nine different murrelet survey datasets from Southeast Alaska (SEAK) and British Columbia (BC) that we examined for statistical power (see Table 2). As noted in the following, some of the original 12 surveys (Table 1) were excluded because of irregular sampling designs, and two datasets were merged. These include surveys conducted throughout SEAK by the U.S. Fish and Wildlife Service as part of a state-wide boat-based seabird monitoring program (Agler et al. 1998; "Agler" in Table 2 and following text) and to ground-truth aerial surveys of SEAK (e.g., Conant et al. 1988, survey conducted by J. Hodges and others; see Appendix F in Piatt et al. 2007; "Hodges" in Table 2, etc.); surveys conducted in Icy Strait by the USFWS and USGS (see Lindell 2005, Appendix G in Piatt et al. 2007; combined surveys #4 and #5 from Table 1; "Icy Strait" in Table 2), by USGS in Glacier Bay (Appendix H in Piatt et al. 2007; only #8 in Table 1 because #6, and #7 used irregular sampling design no longer employed; "Glacier Bay" in Table 2), by the U.S. Forest Service (USFS) throughout SEAK (unpublished data, see Appendix M in Piatt et al. 2007; "US Forest Service" in Table 2, etc.), and at 4 locations in BC (Burger 2002, Burger et al., Appendix D in Piatt et al. 2007; "Broken Inner", "Broken Outer", "Trevor Channel" and "West Coast Trail" in Table 2, etc.). These surveys were boat-based surveys for marine birds, and involved trained observers counting all species (except the US Forest Service and BC) of marine birds along strip or line transects.

APPENDIX B

Following are brief descriptions of each survey protocol (detailed information on these and other survey methods are found in Appendices 1 and 2). For analyses of power to detect trends, we used combined observations of *Brachyramphus* murrelets (marbled, Kittlitz's and unidentified combined) on individual transects of varying length and/or area depending on the survey. Only in Glacier Bay did Kittlitz's Murrelet (*B. brevirostris*) comprise a significant fraction (>1%) of birds observed; otherwise on all surveys most birds were Marbled Murrelets (*B. marmoratus*).

British Columbia Surveys

Four studies were conducted at different locations off the coast of Vancouver Island: Broken Group Islands Inner, Broken Group Islands Outer, Trevor Channel, and West Coast Trail. Field methods were generally similar for these 4 studies, each consisting of a single strip transect 300 m wide (150 m on either side of the boat) (Burger et al., 2002). Data were available for the period 1994 – 2004, though none of the surveys were conducted every year in that period. In years in which surveys were conducted, the transect was surveyed 2 – 6 times between late-April and mid-July.

Data consist of total number of birds counted (both flying and those sitting on the water) along the entire transect on each survey date. Transects are not sub-divided into segments.

Hodges

Boat surveys were conducted by Hodges (reported in Piatt et al., 2007) in support of more extensive aerial surveys, in 1997 – 2001. Different sub-regions of Southeast Alaska were surveyed in August of each year. Each boat survey consisted of several long, continuous coastal transects. Post-processing of data entailed sub-dividing these transects into shorter segments (4.4 km average length) by overlaying a 1 nm grid over the region (to match the scale of Agler surveys). All surveys were treated as if they were strip transects 200 m wide (100 m on either side of the boat).

Data consist of murrelet counts (on water and flying) within each segment, for each year in 1997 – 2001, except 2000.

Agler

Agler et al's study (1998, and also reanalyzed by Piatt et al., 2007) was conducted throughout Southeast Alaska between June 9 and July 27, 1994. The region was classified into coastal (within 200 m of shore) and pelagic (greater than 200 m from shore) strata. A total of 631 transects were randomly selected. Small boats were used to survey transects, treating each as a strip 200 m wide (100 m on either side of the boat).

Data consist of murrelet counts (on water and flying) within each transect.

Icy Strait

Surveys in Icy Strait were conducted by the U.S. Fish and Wildlife Service in 1993, 1995, and 1998, and by the U.S. Geological Survey in all years 1999 – 2003. Both agencies employed similar methods, and followed the same transect through the strait (Piatt et al., 2007). However, 2 repeated surveys of the transect were conducted each year in the first 4 years of the study, while only 1 survey was conducted in each of the last 4 years. Murrelet counts were recorded for each 10-minute segment of the transect. In data post-processing, strip width was treated as 300 m in surveys through 1999, and 200 m for some of the surveys in 2000 – 2003 (where smaller boats were used).

Data consist of murrelet counts (flying and on water) within each 10-minute segment, in each year of the study.

Glacier Bay

Murrelet surveys were conducted in Glacier Bay by the U.S. Geological Survey in 1999 – 2003. Transect lengths were 1.2 – 12.7 km, with median length of 8.8 km. Strip width was 200 or 300 m depending on the vessel. The same route was followed in all years, and in post-survey analyses, transects were divided into segments of ca. 4-6 km in length wherever possible. The resulting breakout of transect segments did not permit identification of spatially coincident transects across years although in general, a similar number of samples were obtained in each year, across similar spatial areas.

Data consist of murrelet counts (flying and on water) within each transect, in each year of the study.

U.S. Forest Service

Surveys for marbled murrelets were conducted in Southeast Alaska by the U.S. Forest Service in 1991 and 1992. Line transects were followed by boat both near the shoreline (100 m from shore) and offshore (500 m or more from shore). For this analysis, we used only the much larger dataset of shoreline transects. Distances to murrelet groups and sizes of groups were recorded, although the vast majority of observations were within 150 m. For the analyses here, birds observed at distances greater than 90 m from the boat were excluded from analyses because there was some indication of bias in counts of birds at exactly 100 m (it appears that observers were "pulling in" more distant birds and inflating 100 m distance estimates). All transects were sub-divided into 2-kilometer segments prior to data collection. The study area was divided into 2 regions or strata: North and South (separated by latitude 57° N).

Data consist of murrelet group size and distance, by segment, transect, region, and year.

ANALYSIS METHODS

In brief, data from each of the surveys described above were used as the basis for simulations of marbled murrelet populations with annual proportional decreases in density. Power to detect these trends was assessed by fitting linear regressions to new (log transformed) data generated by repeated simulations and determining the proportion of regressions with significant negative slope. The details of population simulation varied depending on the type of data available from each survey. However, the method of assessing power via linear regression of log transformed data was the same in all cases.

In simulations for all surveys, effect sizes were chosen to represent annual proportional decrease in population size. For example, an effect size of 0.05 represented a 5% decrease in population size each year. Selected effect sizes were 0, 0.01, 0.02, …, 0.10, i.e., an equally spaced range of values between no trend and a 10% annual decrease. Simulation of no trend allowed assessment of the empirical size of the test. For example, given the nominal size $\alpha = 0.05$, one would expect that of all simulated population trajectories without any real trend, regression estimation would indicate significant ($p < \alpha$) negative trend 5% of the time, purely by chance. Furthermore, in all simulations, population trajectories were generated for years 0 through 19, i.e. 20 years of data. Finally, each simulation for a particular set of conditions (including effect size and sample size) was repeated 1000 times for the assessment of power.

Given the starting 'true' density (D_0), the 'true' density was calculated for each year (t) of the 19-year trajectory using the selected effect size (s) by the formula:

$$D_t = D_0 \times (1 - s)^t$$

where $t = 0, 1, 2, \ldots, 19$. Samples of simulated data with the density D_0 and variance appropriate for a particular study were generated for each segment (transect) of the study. The density in year 0 was then estimated by the mean of simulated density on each segment.

Similarly, the estimated density was simulated in: (1) years 1 through 9 to provide 10 point estimates of density with 9 annual proportional decreases in density, (2) years 1 through 14 to provide 15 point estimates of density with 14 annual proportional decreases in density, and (3) years 1 through 19 to provide 20 point estimates of density with 19 annual proportional decreases in density.

U.S. Forest Service Study

The U.S. Forest Service study was unique in that line transect methods were employed. Distances from the survey boat to murrelet groups had been estimated for each group of murrelets and therefore we used Program Distance (Buckland et al., 1993) to estimate a detection function and then calculate the mean and variance of density in each year (1991 and 1992). The detection function was fit to data from nearshore transects (100 m from shore) only. Similarly, simulations and power analysis for the USFS study are assumed to be representative of nearshore surveys.

When we analyzed the data, we used the Program Distance option to estimate variances by bootstrapping 2-km long segments of the transects, effectively using the number of segments as the sample size in each study rather than the number of observations of groups of murrelets. For estimation of detection probability, distances were truncated beyond 90 m (see *Results*). Program Distance was used to obtain the estimated mean detection probability. We then adjusted the count of murrelets in each segment of transects (i.e., adjusted count = [observed count]/[detection probability]). Once the adjusted counts were obtained and rounded to the nearest integer, power analysis followed the methods described below for strip transect surveys with strip width of 180 m. An arbitrary starting density was selected within the range of densities estimated from Program Distance.

Strip Transect Studies

All surveys other than the USFS survey employed strip transects without adjustment for visibility bias. As with any strip transect survey, we assumed that density based on the counts of murrelets within the strips is an acceptable index for detection of trend in population size over time. Strip transects are widely used for surveying seabirds in Alaska, and most historical surveys have employed strip transect methods (Piatt et al. 2007).

We developed a simulation approach for comparison of these studies so that survey effort could be controlled to the extent possible. Total area surveyed was taken to represent effort, though we recognized that there were other contributors to effort such as size and speed of the boat and number of observers. The values of all these other contributors were not known for all observations in all surveys. Thus, these more complex metrics of effort were not incorporated into our simulations. In addition to areas surveyed in each of the original studies, simulations included selected areas of approximately 44, 110, and 200 km^2 (corresponding to 88, 220, and 400 transects from the Agler survey).

Murrelet counts were simulated within each sample unit, as appropriate for the study (Table 2). To represent the variability in the original data as closely as possible, we first fit negative binomial regression models to the data, using sample unit area as an offset. The general negative binomial model allows for extra dispersion in the data, and thus was preferred over the Poisson model in which the mean and variance are equal. Fitted regression models were of the form

$$\mu(count) = area \times \exp(\mathbf{X}\beta) \tag{1a}$$

$$\sigma^2(count) = \mu + k\mu^2 \tag{1b}$$

where μ was the mean, σ^2 was the variance, β was the coefficient vector, and k was the dispersion parameter. In typical settings, **X** would be a matrix of covariate data. However, here there were no covariates, X was simply a column of 1's , and β represented the intercept only. In effect, β captured the mean response, before adjustment for area of the sample unit.

For several of the studies (Agler, Glacier Bay, Hodges, Icy Strait, and USFS), a few alternative regression models were examined. From simplest to most complex, these included both a common mean and common dispersion parameter for all years or strata (pelagic and shoreline),

separate means but common dispersion parameter, and separate means and dispersion parameters for each year and/or stratum. All models were fit via direct maximization of the log likelihood to obtain estimates of β and k in equations (1a) and (1b). Model alternatives were evaluated using Akaike's Information Criterion, AIC = –2(log likelihood) + $2np$, where np was the number of parameters in the model. Model goodness-of-fit was examined by binning observed counts (O) from the original data and expected counts (E) generated by the fitted model. The chi-squared statistics was calculated as $X^2 = (O - E)^2/E$ and compared to the chi-squared distribution with degrees of freedom equal to the number of bins minus one.

In simulations, sample unit areas were selected as described below for individual studies. Then the expected mean count based on the fitted regression model was calculated for each sample unit and each year in the population trajectory as

$$\hat{\mu}_{i,t} = A_i \exp\left(\hat{\beta}\right)(1-s)^t \tag{2}$$

where i indexed sample units, $t = 0, 1, 2, \ldots, 19$ indexed year, A_i was the area of the ith sample unit, $\hat{\beta}$ was the estimated intercept, and s represented effect size. Note that in Year 0, equation (2) simplifies to equation (1a), and in subsequent years, the last term, i.e., $(1 - s)^t$, accounts for the multiplicative decline in population size.

Determination of the variance in count depended on the study, that is, on the available data and the fitted negative binomial regression model. For the Agler, Glacier Bay, Hodges, Icy Strait, and USFS studies, the dispersion parameter, $\hat{k}_t$, for each year and/or stratum in the simulated population trajectory was selected at random from the set of available estimates. In one common parameterization of the negative binomial distribution with parameters r and p, the mean and variance are, respectively

$$\mu = r(1-p)/p \tag{3a}$$
$$\sigma^2 = r(1-p)/p^2 \tag{3b}$$

By equating (1b) and (3b), and re-arranging terms,

$$p = 1/(1+k\mu) \tag{4a}$$
$$r = \mu p/(1-p) \tag{4b}$$

Thus, using equations (4a) and (4b), $\hat{p}_{i,t}$ and $\hat{r}_{i,t}$ were calculated for each sample unit and year of the trajectory. Simulated murrelet counts with the appropriate means and variances were then obtained from a negative binomial random number generator.

For the British Columbia studies, there were insufficient data to estimate $\hat{k}$ separately for each year; that is, only a common mean and dispersion parameter could be estimated via negative binomial regression. To capture the year-to-year changes in variance, sample variances, $\hat{\sigma}^2$, of

murrelet counts were calculated directly for each year. The negative binomial parameter p was estimated using $\hat{p} = \hat{\mu}/\hat{\sigma}^2$ (by combining and re-arranging (3a) and (3b)); the parameter r was estimated using 4b. Finally, simulated counts were generated from the negative binomial distribution as described above for the Agler and other studies.

The process described above carries some computational burden (fitting a regression model, and simulating counts from a negative binomial distribution). However, that burden is not substantially greater than would be the case with an alternative method for variance estimation such as re-sampling units. Simulating counts can capture the variance appropriately. Furthermore, it permits direct control over both the number and size (i.e., area) of sample units. In the analysis described here, sizes of sample units were chosen to be similar to those in the actual studies. Nonetheless, size could be easily controlled to determine the consequences for power to detect trend. Re-sampling units would not permit such straightforward control over unit area or over the mean count within units.

The sub-sections below detail the differences in simulation methods among the studies.

Hodges and Glacier Bay

Examination of transect segment data from the Hodges and Glacier Bay studies revealed that the normal distribution provided a reasonable approximation to sample unit area, after the appropriate power transformation. Therefore, sample unit areas were generated as normal random variates and then squared for the Hodges study, or raised to the fourth power for the Glacier Bay study. Otherwise, counts within sample units were simulated as described above; that is, negative binomial regression estimates were transformed into parameters suitable for generating random variates from negative binomial distributions.

Icy Strait

Two surveys were conducted in each of the first 4 years of the study and only 1 survey was conducted in each of the remaining 4 years. The best-fitting negative binomial regression model included separate estimates of the mean and dispersion for each of the 12 surveys (see Results below). In simulations, one of the 8 years of the original study was randomly selected with equal probability. Then, if one of the first 4 years had been selected, one of the 2 surveys within that year was randomly selected with equal probability. In effect, surveys from the first 4 years had selection probability of 0.0625 and the remaining surveys had selection probability of 0.125.

Segment areas were not easily approximated by a standard distribution as in the Hodges and Glacier Bay analyses. Therefore, areas were obtained by sampling with replacement from the segment areas within the already-selected survey. Finally, regression parameters from the selected surveys were used to generate counts within transect segments.

Agler

Power analyses were conducted separately for the pelagic and shoreline strata, and for both strata combined. For the stratum-specific analyses, transect areas were obtained by sampling with

replacement from the appropriate subset of observed areas. Regression parameters specific to that stratum were used to generate counts within transects. For the combined power analysis, transects were also randomly selected with replacement. Irrespective of total sample size, the numbers of transects were chosen to maintain fixed proportional contributions from each stratum equal to the proportions in the original data. Areas of selected transects and stratum-appropriate regression parameters were used to simulate counts.

USFS

The USFS study comprised surveys in two regions (North and South) in two years (1991 and 1992). Negative binomial regression parameters were fit separately to each of the four combinations of region and year. Program Distance was used to estimate density of murrelets and group size in each year and region. However, power analysis was conducted for the combined regions, not separately for each region. In the combined analysis, for each year of the simulated population trajectory, one year from the original study was selected at random. Transect segments were allocated equally to the two regions, and counts were simulated within each segment as appropriate for the region and selected year. Transect segments had constant area across region and year, as in the original study. (Note, however, that in the original study, number of transect segments differed region-to-region and year-to-year.)

British Columbia Studies

Total area varied little among surveys (the effective sample units) in these studies. Indeed, area was constant over time for the Broken Inner and Broken Outer studies. Rather than simulating the very slight variation in area for the remaining 2 studies, area was treated as a constant in all 4 studies. Mean survey area was calculated in each study, and was applied in all simulations.

Trend Estimation

The method of trend estimation was chosen to follow methods described in Piatt et al. (2007, and other related reports) as closely as possible. The count within each sample unit was expressed as density (dividing count by area for the strip-transect studies and dividing the adjusted count by area for the line-transect USFS study). The mean and variance of density were calculated across all sample units for each year of the population trajectory. By design, expected values underlying each trajectory followed an exponential decay (though, due to the contribution of variance, realized counts and densities might obscure that underlying pattern). Thus, mean densities were transformed by taking the natural logarithm. The variance of log-transformed density was calculated using a first-order Taylor series approximation

$$\mathrm{Var}\left[\log_e\left(\bar{D}\right)\right] = \frac{1}{\bar{D}^2} \times \frac{\mathrm{Var}\left(\bar{D}\right)}{n}$$

where $\bar{D}$ was the mean of untransformed density and n was the number of sample units.

Weighted linear regression models were fit to the log-transformed data using the inverse variances, $1/\mathrm{Var}\left[\log_e\left(\bar{D}\right)\right]$, as weights. Three models were fit to each 19-year trajectory of

decreasing density: using only the first 10 years of simulated data, using the first 15 years, and using all 20 years. All models were simple linear regressions of log transformed data on years, i.e., year was the explanatory variable. The estimated slopes and associated *p*-values were stored. The entire process (data simulation and trend estimation) was repeated 1000 times for each simulation condition (e.g., combination of effect size and number of sample units).

Power Calculation

For all analyses, the power to detect a trend was calculated as the proportion of 1000 simulations for which the estimated slope was negative and the associated *p*-value was less than the chosen significance level. Three significance levels were examined: $\alpha = 0.05$, 0.10, and 0.15.

Periodic Sampling

In a separate set of simulations, we examined the effect on power of altering the sampling schedule from annual to other periods, such as every other year. These simulations were conducted only for the 4 Southeast Alaska studies that used strip transects. Effort within a year was held constant at a level corresponding to that within the original study. A 21-year population trajectory was generated and then periodic samples were drawn from the trajectory to represent different sampling schedules. The 21-year period was chosen so that the first and last year of the trajectory would be represented in each sampling scheme (every 1, 2, 4, and 5 years). Otherwise, trend estimation and power calculations were performed as described above.

Adjusting Number and Area of Sample Units with Constant Total Effort

In yet another set of independent simulations, the number of sample units and the size of individual sample units were simultaneously controlled such that total effort (i.e., total area sampled) was constant at the level in the original study. That is, number and size of sample units were varied inversely; e.g., when the number was doubled, the area was halved. Number of units was examined at factors of ¼, ½, 1, 2, and 4 times the original number; corresponding area factors were 4, 2, 1, ½, and ¼. For each simulation condition (e.g., ¼ × number, and 4 × area), all individual sample units had the same size. Otherwise, methods were identical to those for the main simulations described above. These simulations were only conducted for the 4 strip transect studies in Southeast Alaska.

RESULTS

USFS Study, Distance Estimation

The 2-km long segments within transects were treated as the sample unit in this analysis. Examination of the data revealed that excessive observations were "stacked up" at 100 m, the largest recorded distance examined in this analysis (observations were made beyond 100m, but we deleted them for our analyses). That is, the histogram depicting frequency of observations as a function of distance indicated declining frequency with increasing distance out to 90 m, as would be expected, but a large spike at 100 m. This spike may have occurred because murrelets

observed beyond 100 m were erroneously assigned a distance of 100 m (we believe this resulted from a bias created by instructing observers to conduct a line transect which would later be compared to densities obtained by truncating the data at 100m to mimic a strip transect). In any case, to minimize bias in distance estimation, observations beyond 90 m were right-truncated.

When restricted to distances less than or equal to 90 m, correlation of group size and distance to detected groups were not significant, ranging from 0.003 to 0.16 in the four data sets. A single detection function was fit to the right-truncated nearshore transect data pooled from both areas and both years, comprising a total of 486 segments with 2141 murrelet observations. The best-fitting detection function, selected by AIC, was based on a uniform key function with a single, simple polynomial expansion term (Table 3, Figure 1). Mean detection probability was 0.719 ± 0.009 (SE).

Program Distance estimated different murrelet group sizes for each region (North and South) in each year (1991 and 1992) (Table 4). Associated density estimates for region and year show that densities were particularly high in the North in 1992 at approximately 86 murrelets/km^2, and otherwise were 25 – 30 murrelets/km^2 (Table 5).

For power analysis, the count of murrelets in each segment was divided by the estimated mean detection probability, 0.719, to correct the observed counts for visibility bias. This detection rate is similar to rates reported in other studies of line transect surveys for murrelets (e.g., 0.74, 0.87, 0.88%; Strong et al. 1995, Becker et al. 1997, Evans Mack et al. 2002). These adjusted counts rounded to the nearest integer were then used to simulate power to detect proportional decreases in density using the same procedures as for the strip-transect studies (see the next section).

Negative Binomial Regression Models

Model selection based on AIC indicated that the more complex models fit the data best. That is, they were fit best by models with separate estimates of mean and dispersion of murrelet count for each year (Glacier Bay and Hodges), each survey (Icy Strait, which had 2 surveys per year in some years), each stratum (Agler, which had pelagic and shoreline strata), or each region and year (USFS, which had 2 regions and 2 survey years). Furthermore, in all studies, models with an offset for area were equivalent or superior to models without the offset.

The four British Columbia studies had relatively little data. While summary statistics (sample means and variances) indicated year-to-year differences in both mean and dispersion of murrelet count, negative binomial regression did not support separate estimates for each year. Maximum likelihood estimation failed to converge for these models. Therefore, simpler models with common mean and dispersion across years were fit to the data. Furthermore, because sample unit area was either constant or nearly so in these studies, there was no advantage (though no disadvantage, either) to including an offset for area in the regression models. Nonetheless, the offset was retained for consistency with the other studies in data simulation.

Chi-squared goodness-of-fit tests indicated that expected counts generated by the fitted negative binomial regression models were consistent with observed data in all 9 studies ($p > 0.10$ in all cases).

Sample variability in density

Sample variability in density (birds/km^2) is presented in Tables 6 and 7 for the original sampling effort in the surveys. The single statistic expected to most influence the power to detect trend over time is the standard error of the mean density, which is directly influenced by the standard deviation in the data and indirectly influenced by the square root of the sample size. This analysis suggests that most Alaska survey transects exhibited low and similar levels of variability (CV means = 12-22%; range = 10-34%) while most BC survey transects exhibited higher levels of variability (CVs means = 25-43%, range = 10-74%)

However, because these CVs depend on original sampling effort, we also calculated estimates of the standard error of mean density when based on an approximate sample size necessary to generate effort of 44 km^2 area surveyed. In other words, if sampling effort (in terms of area) is kept constant among surveys (and drawing upon the pool of all transects from all surveys within and among years to estimate variance), then the ranking of survey CVs changes markedly (Table 8).

Power Analyses

Power to detect declining trends based on the various surveys is depicted in Figures 2 – 9, all representing $\alpha = 0.05$. Power at higher significance levels ($\alpha = 0.10$ and 0.15) is qualitatively similar, and as expected is correspondingly greater. Because simulated population trend is exponential some care is required in interpreting figures. For instance, an annual rate of decline of 5% (equivalently, an effect size of 0.05 as indicated on the X-axis) translates to a total decline of 37.0% with 10 years of data (9 years of decline), 51.2% with 15 years of data (14 years of decline), and 62.3% with 20 years of data (19 years of decline). Table 9 contains total proportional decrease in population size over periods with10, 15, and 20 years of data as a function of annual proportional decrease (simulation effect size) ranging from 0.0 to 0.1 per year.

The best way to compare relative power of the studies is to determine the annual rate of decline associated with a given power in a fixed number of years. For example, Figure 2a (Agler study) has a horizontal dashed line drawn at 80% power intersecting the power curve for 15 years of data at approximately 0.017 annual rate of decline. In other words, the power to detect an annual rate of decline of approximately 1.7% with 15 years of data (i.e., an overall decline of 23% in 15 years) is estimated to be 80%. As illustrated in Figure 2d, estimated 80% power for Icy Strait is associated with an annual rate of decline of approximately 3.2% for 15 years of data (i.e., an overall decline of 39% in 15 years). The inference is that with 80% power in 15 years, the Agler study is likely to detect a smaller annual rate of decline than the Icy Strait study (recall however, that the Icy Strait has less effort in the original study design)

Another way to consider these data is to calculate the annual rate of decline corresponding to an overall decline of 50% for a population trajectory of any length, and then find the associated rate of annual decline. For instance, a 50% decline observed over 10, 15, or 20 years of data collection (9, 14, or 19 years of decline) would correspond to annual declines of 7.4%, 4.8%, or

3.6%, respectively. Thus, the power to detect a 50% decline in the Icy Strait study with 10, 15, and 20 years of data is approximately 0.9, 0.98, and 0.99, respectively (Figure2d).

Among the 5 Southeast Alaska studies, power was greatest for the Agler study, slightly lower for the Glacier Bay, Hodges, and US Forest Service studies, and considerably lower for the Icy Strait study (Figure 2). Differences among the 4 British Columbia studies were more pronounced, power was greatest for the Trevor Channel study and lowest for the West Coast Trail study (Figure 3). Most BC surveys had much less power than Alaskan surveys, and only the Trevor Channel study fell within the range of power observed in Alaska.

The effects of controlling for sampling effort are shown in Figures 4 – 9. Total effort in terms of total area surveyed per year is the same within each row across all 6 figures (e.g., 44 km^2/year in the top row). In all cases, increasing total effort (by increasing the number of segments or transects but holding surveyed area constant) leads to progressively greater power. Figure 4 shows power for the Agler study by stratum (pelagic and shoreline). Power is slightly greater in shoreline surveys, though the differences are slight (compare panels a, c, and e to panels b, d, and f, respectively). The effects of varying total effort for all studies in Alaska and British Columbia are shown in Figures 5 – 9 (note that in Figure 5, results from both the pelagic and shoreline strata in Agler surveys are combined). Power is similar at a given level of total effort for all 5 Alaska studies (Figures 5, 6, 7), even though the number of sample units (transects or transect segments) surveyed varies considerably. For example, 17 transects from the Glacier Bay study (Figure 5b) would be roughly equivalent to 44 km^2, whereas the same area would be represented by 100 transects in the Hodges study (Figure 6a). Only the USFS surveys seem to stand out, having higher power across all levels of sampling effort than the other four Alaska surveys.

Patterns are not so consistent among the 4 British Columbia studies (Figures 8, 9); that is, power varies more widely among these studies at a given level of effort than among the Alaska studies. For instance, power is much greater for the Broken Inner studies than for the West Coast Trail study at any level of effort (compare Figures 8a,c,e to Figures 9b,d,f). Recall that the sample unit for the British Columbia studies is the entire survey conducted on a particular date, not the transect or transect segment as in the Alaska studies. Therefore variability in the BC data represents temporal variability whereas variability in the Alaska data represents both spatial variability among transects and – except for the Agler study – temporal variability (all the Alaska surveys required multiple days, weeks or months to complete, and so unaccounted-for temporal variability exists in all surveys at daily, weekly, and seasonal scales). Number of sample units is especially small for the Trevor and West Coast Trail studies; e.g., 44 km^2 is represented by only 2 West Coast Trail surveys and only 3 Trevor surveys.

Periodic sampling for 20 years at other than annual frequency results in reduced power (Figure 10), although this effect was less pronounced when power was already high. Differences among surveys (Figure 10) really reflect the differences among original survey effort (see above). Sampling every 2 years, every 4 years, or every 5 years results in relatively little loss of power to detect significant trends in population decline over 20 years of data, except in the case of Icy Strait (again, lower because original sampling was smaller). Indeed, the loss of power that would result from halving the annual sampling rate from every year to every second year is of a much smaller magnitude than the loss of power that would result from: (a) halving the survey duration

from 20 to 10 years (e.g., Figure 2), or (b) halving the annual survey effort from, for example, 100 km^2 to 50 km^2 (Figure 4).

The last two sets of figures consider the power to detect declines in populations density over 10, 15, or 20 years when total effort (area) is held constant, but the number of transects and size of transects is varied. Results clearly demonstrate that power decreases with decreasing number of sample units (Figures 11, 12). This also demonstrates the importance of assigning transect length in designing a survey. Much attention is usually given to selecting the proportion of total habitat to be sampled (e.g., Agler et al. 1998), but the selection of sampling unit area has been almost arbitrary, or at least subjective (Schneider and Piatt 1986, Piatt et al. 2007). Clearly, it can have as much influence on power to detect change as survey duration, survey effort, and frequency of sampling.

CONCLUSIONS

Do any of these surveys stand out as "best way" to survey murrelets in SE Alaska?

Surveys using spatial samples of relatively large areas.

Only one of the surveys we examined (Agler) was designed from the outset to census murrelets throughout SE Alaska. But, our question here is: Would any of the other methods be better or worse for surveying murrelets in SE Alaska? Given 10 to 20 years of data and with a proportional decrease in density (effect size) from 0.01 to 0.1 per year, we found that there is little difference in power of the southeast Alaska studies to detect a significant slope when log-transformed data are regressed against time with a linear model (Figure 2). The surveys in Icy Strait are the exception, though effort per survey, measured as area surveyed, was less. When the effort was standardized among the southeast Alaska studies (Figures 4 – 7), power of the Icy Strait surveys was comparable to the other studies. The USFS surveys offered slightly higher power than other methods.

These simulations were conducted by starting with an assumed density in year 0, with a 'true' density decreasing in a smooth exponential manner over the time periods. Simulated data each year was generated using the mean on the smooth curve with variance randomly selected among the variances from available years (and in some cases, regions) of original data. Standard errors in the southeast Alaska surveys, when standardized to 44 km^2 of survey area, ranged from 5.33 to 8.95 (Table 8). The strong message is that power to detect a negative slope in the linear model over 10 to 20 years for this range of standard errors of the mean density does not vary much among survey methods. Therefore, in practice, the most important consideration is not the exact survey methodology, but rather that methods should be standardized across investigators and years, and should be conducted during that part of the breeding season determined to be least variable for attendance of birds at sea (as much as possible).

Surveys using temporal samples of relatively small areas within years.

The British Columbia studies utilized multiple surveys within a summer of relatively small areas with no (or very little) variation in the area surveyed. Power was estimated by measuring annual variation among the surveys conducted repeatedly in each summer. When the total area surveyed was standardized at 44 km^2, corresponding to a relatively large number of surveys each summer (10 to 16 in the Broken Inner and Broken Outer studies, Figure 8), there is little practical difference in power to detect declines in population density when compared to the Southeast Alaska surveys. However, when the number of annual surveys is relatively small (2 to 3 in the Trevor and West Coast Trail studies, Figure 9), power drops by an important amount.

Conclusion.

Given 10 to 20 years of sample data, our professional judgment is that surveys of spatial samples over a relatively large area of SE Alaska should be recommended. This recommendation is based not only on power, but the ability to draw inferences to a relatively large segment of the murrelet population with survey units well interspersed within the survey area.

That being said, there is a trade-off between spatial and temporal sampling. Ideally, a robust survey would sample the entire 35,000 square km region of SE Alaska multiple times in a summer to capture both spatial and seasonal variability in numbers. This is impossible, however, because it takes 6 or more weeks to survey this vast region. Therefore, we would recommend infrequent SE Alaska-wide surveys be combined with intensive small-spatial-scale surveys in selected locations that will permit multiple seasonal surveys at more frequent annual schedules. Given similar levels of area surveyed, both methods would retain similar power to detect trends.

Which is better to detect long term trends in population size: strip transect surveys or line transect (distance sampling) surveys?

Line transect surveys (distance sampling) are designed to primarily reduce the bias in estimation of density of animals, not to improve the estimate of the variance of the estimated density. Original published formula and computer software programs often incorrectly considered the animals or groups of animals detected in line transect surveys to be independent and the number of detections to be the 'sample size'. Bias is corrected under the realization that not all individuals are counted in strip transect surveys and that, in general, probability of detection decreases with increasing distance of individuals or groups from the survey line. Variance in a line transect survey is properly estimated using bootstrapping (re-sampling) procedures where physical segments of the survey line are sampled with replacement, say 1000 times, and variance of the resulting estimates computed.

Note that the asymptotic confidence intervals reported in Table 4 are wider than the bootstrap percentile confidence intervals indicating that the assumption of independent detections is not appropriate for the US Forest Service data. From a practical point of view there is not much difference in the width of the confidence intervals, however this may not be the case in the future or in other regions.

An alternative estimate of variance can be obtained by estimating the average probability of detection, adjusting the original counts in each segment, and computing the variance of the adjusted counts following the same methods as would be used to estimate the variance of the index on density obtained from strip transect surveys. We adjusted the original counts in the US Forest Service survey using the average detection probability and simulated power to detect annual proportional decreases in the density using the same methods as used for the strip transect surveys (Figure 2e and Figure 7).

Conclusion

Given 10 to 20 years of line transect survey data following the US Forest Service protocol, there is only a slight improvement in the power to detect a given annual proportional decrease in density when compared to the protocols used to obtain an index on density in the strip transect surveys (Figures 4, 5, 6, and 7). We are comparing line versus strip transects conducted at different times and places, so it is not clear whether the increase in power is due only to the survey protocol. However, Becker et al. (1997) found a very similar result in comparing the power of line and strip transects conducted by observers simultaneously. He noted only slight improvement in power of line transects, but the difference became more noticeable after 5 or more years of sampling. We grant that line transect surveys will result in decreased bias in estimation of density of murrelets (and therefore population estimates), and possibly a slight increase in power to detect trends, but this advantage must be weighted against the increased effort required to measure distances to detected individuals or groups for all species of interest.

How much sampling effort is required to obtain adequate power to detect important declines (increases) in density?

A famous statistician with a sense of humor, Dr. Doug Johnson (U.S. Geological Survey), once said that the answer to the question of how large the sample size should be is to spend all of the money. This answer has a lot of truth in it. Difficulties begin with the fact that there is always more than one parameter or species of interest in monitoring studies (all of the texts and references essentially deal with one variable at a time) and a design that is optimal for one will not necessarily be best for the others. Also, betting on the future variation in data based on variation from the past has its own obvious drawbacks. Regardless, we must do it, otherwise no administrator will approve funding for the work.

A rule of thumb is to plan for 80% power to detect a 50% reduction in density with 15 years of data. This corresponds to 80% power to detect approximately an annual proportional decrease of 0.048 = 4.8% per year for 15 years (Table 9). This criterion is exceeded in our simulations by the five surveys (Agler, Glacier Bay, Hodges, Icy Strait, and US Forest Service) at or below 44 km^2 of survey effort, e.g., 94 transects in the Agler survey (Figures 5, 6, and 7). There were two decisions made in the simulation methods that tend to make this recommendation conservative: 1) as density decreases it is expected that the variance of density in a sample survey will decrease, whereas we continued to randomly sample dispersion parameters from among years and regions (variance in estimated density is determined by both the mean, which decreased each year, and the dispersion parameter of the fitted negative binomial distribution), and, 2) we report power with the size of the test $\alpha = 5\%$, a conservative level in field monitoring studies.

However, the assumption of a smooth proportional decrease from a fixed density in year 0, tends to underestimate the variance of real data about a model for the trend in density over, e.g., 15 years, because reality is that 'true' density of a population will not decrease exactly 4.8% per year. This extra variance in real data will tend to make our simulated power curves optimistic (too high) even when a reduction of 50% in the density occurs in, e.g., 15 years.

Conclusion

To achieve the level of power described above, total sampling effort per year should be somewhat more than 44 km^2 per year, or equivalently something like 100 transects in the Agler survey or 120 segments in the US Forest Service survey, well interspersed throughout the study area by a systematic procedure (see comments on random versus systematic sampling and size of segments/transects below).

Which is better, random or systematic placement of segments/transects in a survey?

Information on this issue was not included specifically in the simulations, but with respect to power of surveys to detect change, the Agler surveys performed about average of all the surveys we examined. With regard to other statistical issues, the answer to this question is that surveys can almost always be designed so that systematic placement of segments/transects is better than random or stratified random placement.

Placement of the sampling units must be made by some probabilistic procedure and must provide good interspersion throughout the area of interest. Probabilistic location and good interspersion of units provide the logical basis for making valid statistical inferences to the study area that will stand the test of time. Independence of measurements on units is often stated as a third requirement and is the natural result of some probabilistic procedures, e.g., simple random sampling. However, systematic sampling plans are very successful, despite lacking the absolute guarantee of mathematical 'independence' as defined in books on sampling procedures. Almost always, systematic sampling plans can be designed so that results are more precise than those obtained using equivalent effort with simple random sampling or stratified random sampling (Manly 2001). Analyses of data from systematic designs that are analyzed as if they are from a 'random' design are usually conservative (i.e., estimated standard errors are too large and confidence intervals are too wide). The exception is when there is some cyclic variation, so that regularly spaced units tend to fall into the cyclic pattern to produce biased results, e.g., the units always land on the points of the shoreline and not in the bays, a situation that can be avoided in practical situations. Another problem with systematic placement of segments/transects is that it is relatively difficult to increase or decrease the number of units (sample size) and maintain the spatial balance in the original survey.

General randomized tessellation stratified (GRTS) samples (McDonald (http://www.west-inc.com, GRTS for the Average Joe: A GRTS Sampler for Windows), Stevens and Olsen 1999) are gaining popularity as a sampling scheme for large-scale long-term environmental surveys. GRTS samples are designed such that for any sample size, say n, the first n units in the sample will be spatially balanced (i.e., good interspersion). A spatially balanced GRTS sample makes it easy to both add or remove units in a way that does not compromise spatial balance. The ease

with which spatially balanced units are added or removed is the chief advantage of GRTS samples over the next-most popular design, systematic sampling.

Conclusion

We recommend use of a GRTS sample for the reasons given above. However, if consistent sampling effort can be maintained, the simplicity of segments/transects that are systematically interspersed along the coastline and in the pelagic zone has a lot to recommend it (taking care to avoid alignment of systematically located units with potential cyclic reoccurrence of physical features that may be correlated with density of murrelets). There is clearly nothing wrong with random sampling from a statistical perspective. Random sampling has the advantage of simplifying analysis, however it adds some logistical constraints. Finally, one of the authors (McDonald) stated he often did not like the interspersion of units provided by random or stratified random procedures in applications and ended up re-sampling, obviously an act that is quietly buried and not mentioned in final reports.

Is it necessary for surveys to be conducted every year to have adequate power to detect trend in density?

The short answer is no, however tradeoffs exits between the level of survey effort and the interval between surveys. We simulated the power to detect annual proportional decreases in density in a 20 year trajectory by using semi-annual sampling (11 data points), skipping 3 years (6 data points), and skipping 4 years (5 data points) for the strip transect surveys: Agler, Glacier Bay, Hodges and Icy Strait. Sampling effort was least in the original Icy Strait survey where the criterion of 80% power to detect a 50% reduction in density in 20 years is met with samples taken every third year (interpolate between the curves for samples every other year and every fourth year in Figure 10 d to obtain an effect size of approximately 3.6%). Original sampling effort in the Icy Strait studies was 79 transects, somewhat more than 44 km^2 (56 transects) discussed above.

Conclusion

We recommend sampling every other year if the minimum recommended sampling effort of approximately 44 km^2 were to be used. If sampling were conducted every third year (six data points in 15 years or seven data points in 18 years; not considered in our simulations) it should meet the minimum criterion for power, especially if sampling effort on each occasion were to be increased somewhat.

How long should the segments/transects be?

Protocols for the width of the strip transects are well established so if we wish to adjust the area of coverage provided by sample units, then the question comes down to the length of the segments/transects. A well known principle of study design is that the shape and size of units should be selected so as to minimize the variance between statistics measured on the units. For example, quadrates in vegetation sampling should run parallel to any gradient rather than perpendicular to a gradient in plant density. In animal surveys, the same principle applies, i.e.,

the objective should be to select unit size so as to avoid a few extremely large values and lots of extremely small values (zeros),

Among the four strip transect surveys, Glacier Bay had the longest transects, followed by Icy Strait, Agler, and Hodges. We were expecting to see different patterns among the power curves as we varied the size of units in the four studies (Figures 11 and 12), but relative change in power was very similar among the studies as the length of transects changed. These simulations seem to reinforce the generally held principle that, everything else held constant, more smaller units, well interspersed throughout a study area, results in smaller variance with increased power to detect trends. In reflecting on the simulations, we may not have been successful in attacking the problem in that the negative binomial model may not have captured the actual variances appropriately as the size of the units was changed.

Conclusion

The jury is still out on the value of our simulations to address the effect of varying transect length on variance and the resulting power in these surveys. It is tempting to employ very short transects so as to increase power, but this seems arbitrary and creates logistical problems in implementation of surveys. Other issues, such as selection of the transect length to capture the patch scale of target species to reduce variance or achieve approximately uncorrelated counts; must also be considered when selecting size of sampling units (Schneider and Piatt 1986, Burger et al. 2004b). With this in mind, it appears that sampling units of 0.5 to 1.0 km^2 are desirable.

Should sampling units be permanent or temporary?

The simulations conducted do not directly address this question, however, our professional judgment and experience is that using exactly the same sample units in repeated surveys results in lower spatial variance and increased power to detect trends. The assumption is that sample size and interspersion of units is adequate to generate estimates that are highly correlated with overall population changes. While every unique sample is biased high or low, all we can hope for is that the bias is small and that estimates are highly correlated with overall population changes.

The relative advantages of selecting a new sample of units each year would be: 1) that the estimates give a better overall idea of status (if line transect sampling were conducted and biases of the index strip transect surveys are adequately corrected) and 2) researchers get to see more of the study area and to learn about use of unique habitats that might otherwise be overlooked.

Conclusion

We recommend survey of exactly the same set of units in repeated spatial surveys.

Overall recommendation for future murrelet surveys in southeast Alaska.

1) Given that 10 to 20 years of sample data will be collected, our professional judgment is that strip transect surveys of the same spatial sample over the entire SE Alaska area should be conducted under the assumption that more species than murrelets will be surveyed. Our analysis

suggests that for murrelets it makes little difference which counting protocol (line versus strip), platform (skiff versus ship), or sampling layout (random versus systematic) one employs, but methods should be standardized in any case. In contrast, sampling effort (sample unit area, frequency of sampling) and total area being sampled are very important issues to sort out in advance.

2) We make the weak recommendation that segments/transects be of size comparable to the Icy Strait segments (ca. 0.8 km^2) which were determined in previous analyses to be largely uncorrelated (Piatt et al. 2007). Segments/transects should be well interspersed throughout the study area by the GRTS procedure or a systematic sampling procedure. Surveys every third year with total effort comparable to that in the Icy Strait surveys should give 80% power to detect a 50% decline in population density in 20 years (at the $\alpha = 5\%$ level of testing and under the assumption that the decline is relatively smooth). From a practical standpoint, it may not be possible to sample the entire Southeast Alaska area every third year. Our simulations indicate that surveys conducted every 5 years with sampling effort between that of the Icy Strait and Glacier Bay surveys will meet the same criterion of 80% power to detect a 50% decline in population density in 20 years.

3) Minimum total effort should be at least 44 km^2 of surveyed area with the survey effort in the Icy Strait study (ca. 70 km^2) as a more reasonable minimum target. Since this suggestion for minimum effort is based on the rule of thumb for 80% power to detect a 50% reduction in density with 15 years of data, any desire to have higher power, resolve trends in shorter times, resolve lesser rates of decline, or sample less frequently, would require increasing the sampling effort by some corresponding amount.

4) Similar power to detect trends could be obtained by conducting repeated surveys of a small area (for example, 7 repetitions of a 10 km^2 survey). We recommend this kind of sampling to assess local-scale trends in different areas of SE Alaska and provide more "real-time" information on annual variability.

5) If only murrelets are of interest, line transect (distance sampling) methods should be used to minimize bias in estimation of the status of the population (but recognizing that line transect sampling does not improve power to detect trends relative to strip transects as long as strip transect survey protocols remain constant and sample sizes are sufficient for the index on density to be highly correlated with total density). It is possible to combine methods: conduct strip transects for most species and simultaneously conduct line transects for murrelets, and this may be a reasonable compromise.

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Table 1. At-Sea Surveys for *Brachyramphus* Murrelets in SE Alaska and British Columbia
Note: timing, area surveyed, and replications include data used for murrelet power analysis only.

No.	Survey Name	Agency	Timing	Year	Location	Area (km^2)
1	Agler et al	USFWS	9 June to 27 July	1994	SE Alaska	297
2	Hodges et al	USFWS	1 August to 13 August	1997-2001	SE Alaska	748
3	USFS Nearshore Surveys	USFS	18 May-16 August	1991-1992	SE Alaska	501
4	Lindell-Icy Strait	USFWS	14 June-16 July	1993-1999	Icy Strait	70
5	USGS-Icy Strait	USGS	11 June-23 June	1999-2003	Icy Strait	72 or 52
6	Piatt - Glacier Bay	USFWS	15 June- 15 July	1991	Glacier Bay	145
7	Lindell-Glacier Bay	USFWS	15 June - 15 July	1993	Glacier Bay	84
8	USGS-Glacier Bay	USGS	11 June-23 June	1999-2003	Glacier Bay	250
9	Trevor Channel-transect	Univ. of Victoria	Seasonal (May-Aug)	1994-2000	Trevor Channel BC	12.9
10	Broken Group Inner	Parks Canada	Seasonal (May-Aug)	1995-2006	Broken Group Is (BC)	2.8
11	Broken Group Outer	Parks Canada	Seasonal (May-Aug)	1995-2006	Broken Group Is (BC)	4.4
12	West Coast Trail	Parks Canada	Seasonal (May-Aug)	1994-2006	West Coast Trail (BC)	19.4

Table 2. Summary of datasets examined for statistical power.

Study	Sample Unit	Sample Size	Approximate Mean Unit Size (km^2)
Agler	transect	631	0.5
Glacier Bay	segment	105 – 110 / year	2.6
Hodges	segment	295 – 663 / year	0.4
Icy Strait	segment	69 – 90 / survey	0.8
US Forest Service	segment	196 – 277 / year	0.4
Broken Inner	survey date = transect	2 – 5 / year	2.8
Broken Outer	survey date = transect	2 – 5 / year	4.4
Trevor Channel	survey date = transect	5 – 7 / year	12.8
West Coast Trail	survey date = transect	2 – 5 / year	19.8

Table 3. Models for detection function examined using Program Distance, ranked by AIC.

Key Function	Expansion	# Terms	AIC
Uniform	Simple Polynomials	1	9129
Half-normal	Hermite Polynomials	2	9132
Hazard Rate	Cosines	1	9138
Uniform	Cosines	2	9146
Negative Exponential	Cosines	2	9148

Table 4. Murrelet group sizes by region and year, estimated by Program Distance. SE = standard error.

					Group Size	
Region	Year	# Segments	Area (km^2)	# Observations	Mean	SE
North	1991	89	32.04	189	2.952	0.249
	1992	154	55.44	1361	2.520	0.105
South	1991	197	70.92	413	3.746	0.402
	1992	46	16.56	178	1.691	0.070

Table 5. Murrelet density estimates by region and year, from Program Distance. SE = standard error, LC = lower confidence limit, UC = upper confidence limit. Both asymptotic and bootstrap percentile confidence limits are reported.

				Asymptotic		Bootstrap	
Region	Year	Estimate	SE	95% LC	95% UC	95% LC	95% UC
North	1991	24.226	5.916	15.038	39.027	12.420	41.334
	1992	86.061	9.629	69.075	107.230	66.100	123.020
South	1991	30.343	4.876	22.172	41.525	21.877	41.154
	1992	25.284	4.459	17.793	35.929	17.648	36.498

Table 6. Sample variability in density (birds/km^2), Southeast Alaska studies (using sample size from original survey). Mean density = (standard deviation)/(coefficient of variation) = (standard error of mean density)/(CV mean density).

Study Stratum	n	Standard Deviation	Coefficient of Variation	CV Mean Density	Standard Error of Mean Density
Agler	**631**	**67.2330**	**3.3028**	**0.131**	**2.67**
Pelagic	440	72.6873	3.2428	0.155	
Shoreline	191	52.4246	3.3574	0.243	
Glacier Bay	**542**	**21.9815**	**1.2567**	**0.054**	**0.944**
1999	110	30.1550	1.4565	0.139	
2000	109	18.6257	1.1521	0.110	
2001	105	23.0188	1.0758	0.105	
2002	109	17.8570	1.2746	0.122	
2003	109	16.8054	1.0988	0.105	
Annual Mean				0.116	
Hodges	**1704**	**65.2256**	**6.9825**	**0.169**	**1.57**
1997	663	101.6963	8.6593	0.336	
1998	374	9.9250	2.4261	0.125	
1999	295	21.1256	2.3262	0.135	
2001	372	24.1326	2.2889	0.119	
Annual Mean				0.179	
IcyStrait	**941**	**45.6283**	**2.0587**	**0.067**	**1.48**
FWS-1	71	63.2435	1.2477	0.148	
FWS-2	71	50.5467	1.4563	0.173	
FWS-3	69	71.1491	1.7801	0.214	
FWS-4	74	65.2628	2.0061	0.233	
FWS-5	77	34.5292	1.9870	0.226	
FWS-6	84	32.5281	2.8415	0.310	
FWS-7	77	40.8590	2.9242	0.333	
USGS-1	88	7.9135	1.6998	0.181	
USGS-2	79	30.0665	2.0613	0.232	
USGS-3	79	41.2083	1.6010	0.180	
USGS-4	90	35.5592	2.3496	0.248	
USGS-5	82	27.4699	1.7402	0.192	
Annual Mean				0.223	
USFS	**473**	**98.8383**	**2.0734**	**0.095**	**4.545**
1991	233	67.8961	2.3108	0.134	
1992	240	126.3290	1.7193	0.123	
Annual Mean				0.129	

Table 7. Sample variability in density (birds/km^2), British Columbia studies (using sample sizes from original surveys). Mean density = (standard deviation)/(coefficient of variation) = (standard error of mean density)/(CV mean density).

Study Stratum	n	Standard Deviation	Coefficient of Variation	CV Mean Density	Standard Error of Mean Density
Broken Inner	**30**	**6.2705**	**0.8059**	**0.147**	**1.14**
1995	2	6.3978	0.3571	0.253	
1996	4	3.9466	0.4235	0.212	
1999	3	4.3178	0.8948	0.517	
2000	5	4.5232	0.7910	0.354	
2001	3	7.5252	1.0755	0.621	
2002	4	8.2185	1.0093	0.505	
2003	4	6.8158	1.0463	0.523	
2004	5	7.1902	0.9551	0.427	
Annual Mean				0.427	
Broken Outer	**31**	**8.2619**	**0.7250**	**0.130**	**1.48**
1995	2	12.3037	0.4071	0.288	
1996	3	7.1708	0.4474	0.258	
1999	5	3.1080	0.3202	0.143	
2000	5	5.4096	0.4579	0.205	
2001	2	1.7805	0.6221	0.440	
2002	4	10.6228	1.0427	0.521	
2003	5	6.4114	0.5344	0.239	
2004	5	3.6030	0.5872	0.263	
Annual Mean				0.295	
Trevor Channel	**36**	**10.2566**	**0.7033**	**0.117**	**1.71**
1995	7	7.8301	0.4494	0.170	
1996	5	18.3772	0.8980	0.402	
1997	6	11.5592	0.6287	0.257	
1998	6	5.8581	0.5202	0.212	
1999	6	9.6555	0.8341	0.341	
2000	6	2.3248	0.2612	0.107	
Annual Mean				0.248	
West Coast Trail	**25**	**27.3004**	**0.6346**	**0.127**	**5.46**
1994	3	16.1478	0.2383	0.138	
1995	3	35.2142	0.5714	0.330	
1996	2	58.0768	0.9930	0.702	
1999	2	10.2523	0.7455	0.527	
2000	2	20.3590	0.7813	0.552	
2001	2	14.5586	0.4337	0.307	
2002	2	27.5107	1.0373	0.733	
2003	5	24.0871	0.4902	0.219	
2004	4	14.1245	0.4521	0.226	
Annual Mean				0.415	

Table 8. Variability in density (birds/km^2)of birds on survey, adjusted for constant effort. n(44) = number of sample units representing approximately 44 km^2 . Mean density = (standard error of mean density)/(CV mean density).

Study	Standard Deviation	n(44)	Coefficient Variation of Mean Density	Standard Error of Mean Density
Agler	67.23	94	0.34	6.93
Pelagic	72.69	132	0.28	6.32
Shoreline	52.42	56	0.45	7.00
Glacier Bay	21.98	17	0.30	5.33
Hodges	65.23	100	0.70	6.52
IcyStrait	45.63	56	0.28	6.09
Broken Inner	6.27	16	0.20	1.57
Broken Outer	8.26	10	0.23	2.61
Trevor Channel	10.26	3	0.41	5.92
West Coast Trail	27.30	2	0.45	19.3
USFS	98.83	122	0.19	8.95

Table 9. Total proportional decrease in population size over periods with10, 15, and 20 years of data as a function of annual proportional decrease (simulation effect size).

	Annual Proportional Decrease										
Years	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
10	0.000	0.087	0.166	0.240	0.308	0.370	0.427	0.480	0.528	0.572	0.613
15	0.000	0.131	0.246	0.347	0.435	0.512	0.580	0.638	0.689	0.733	0.771
20	0.000	0.174	0.319	0.439	0.540	0.623	0.691	0.748	0.795	0.833	0.865

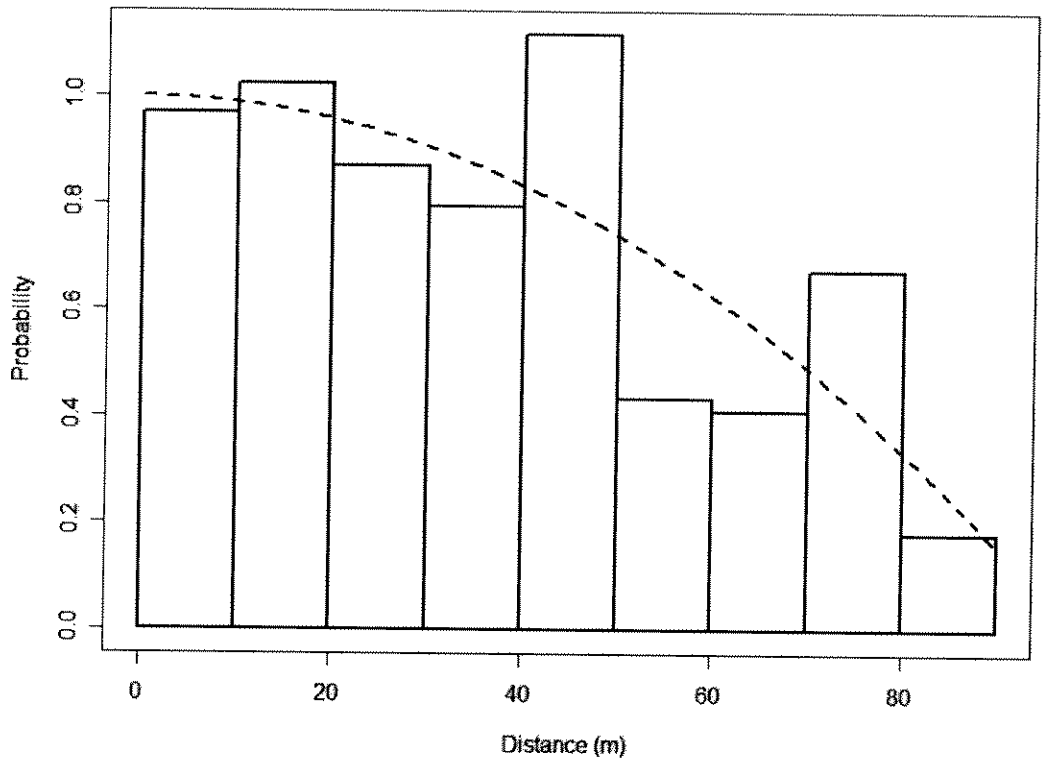

Figure 1. Histogram of nearshore murrelet observations on USFS surveys as a function of distance from the survey boat, and detection function (dashed line) estimated using Program Distance.

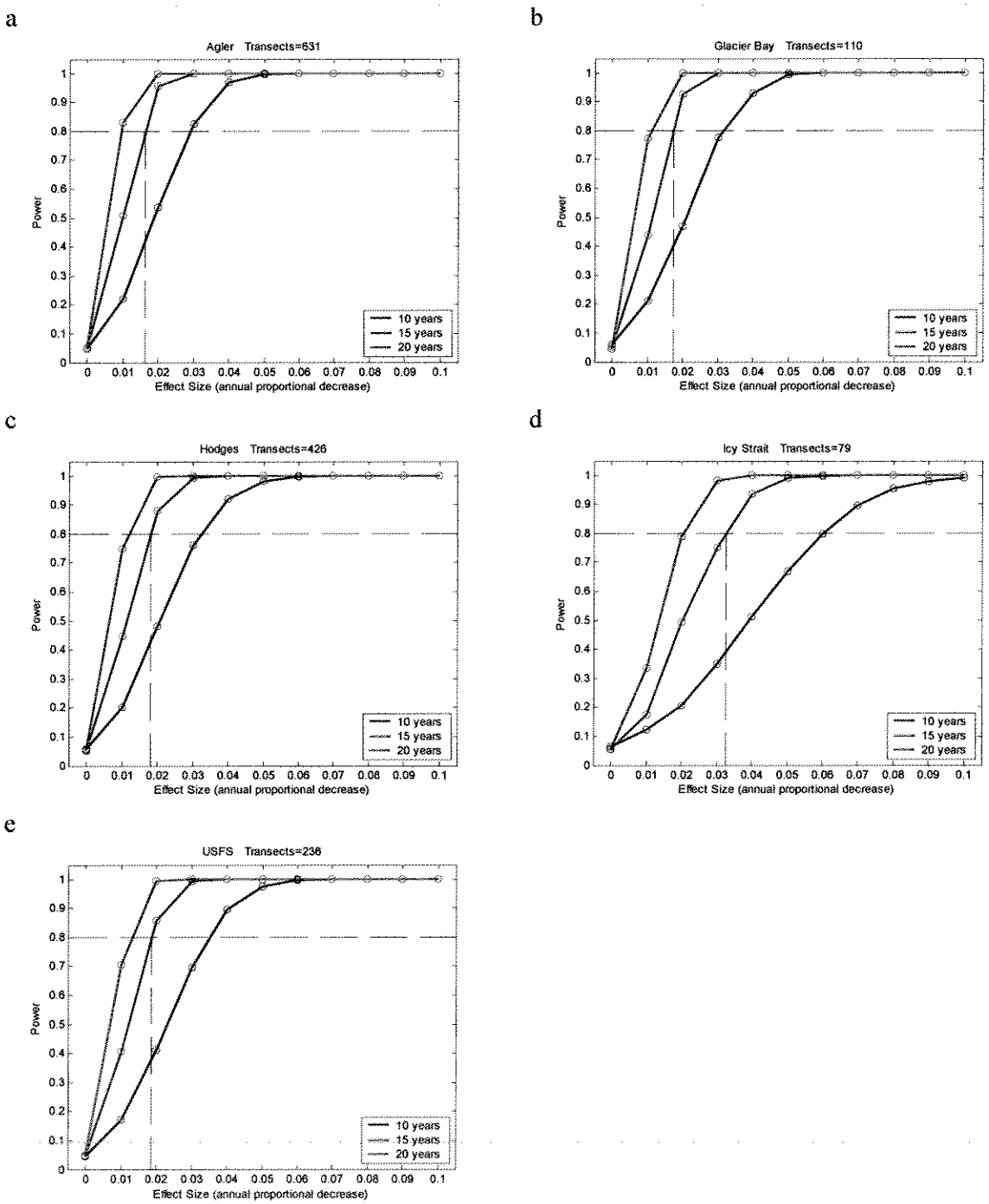

Figure 2. Power to detect trend in declining populations in Southeast Alaska for 10 years (blue), 15 years (green), and 20 years (red) at level of survey effort comparable to original survey, at $\alpha = 0.05$. (a) Agler (631 transects or 297 km^2 per year); (b) Glacier Bay (110 transects or 280 km^2 per year); (c) Hodges (426 transects or 187 km^2 per year); (d) Icy Strait (79 transects or 62 km^2 per year); (e) USFS (236 transects or 85 km^2 per year).

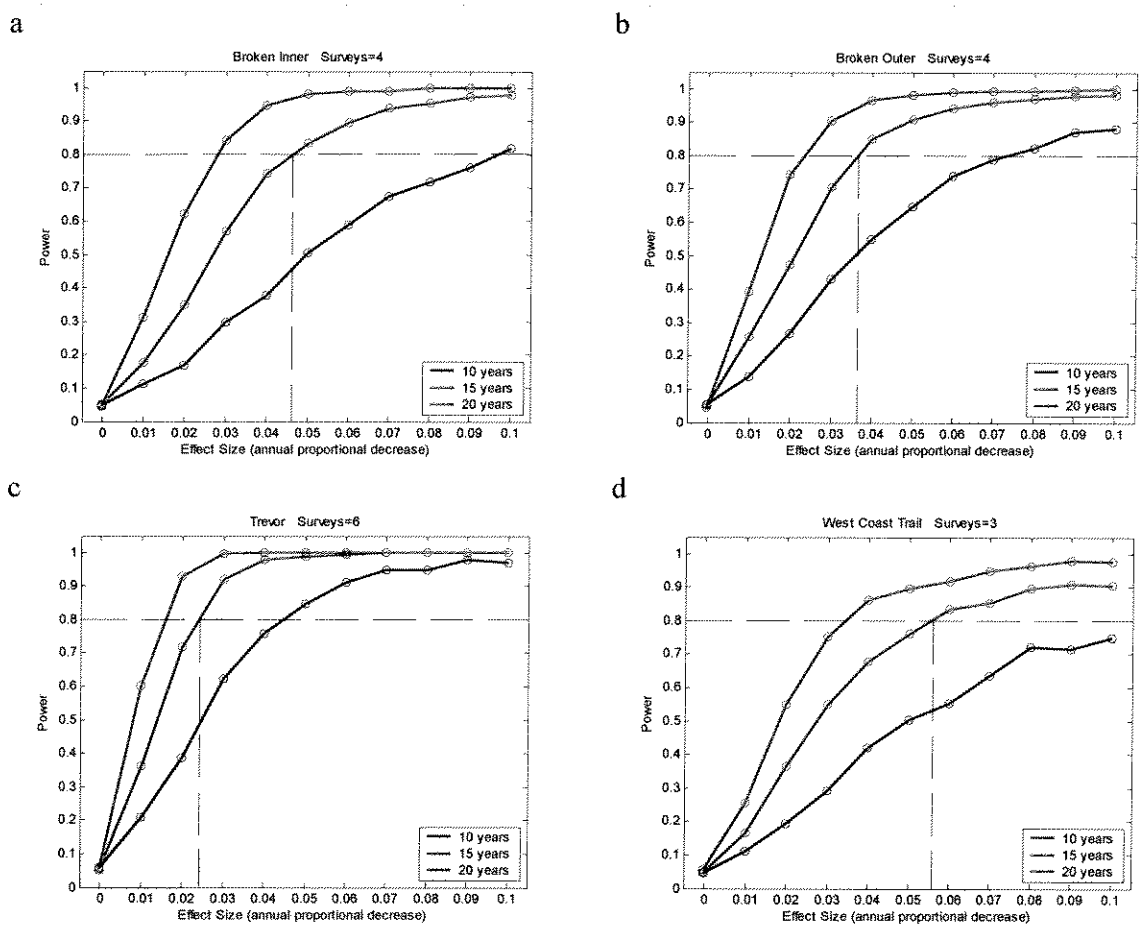

Figure 3. Power to detect trend in declining populations in British Columbia for 10 years (blue), 15 years (green), and 20 years (red) at level of survey effort comparable to original survey, at $\alpha = 0.05$. (a) Broken Inner (4 surveys/year, 11 km^2); (b) Broken Outer (4 surveys/year, 17 km^2); (c) Trevor (6 surveys/year, 77 km^2); (d) West Coast Trail (3 surveys/year, 59 km^2)

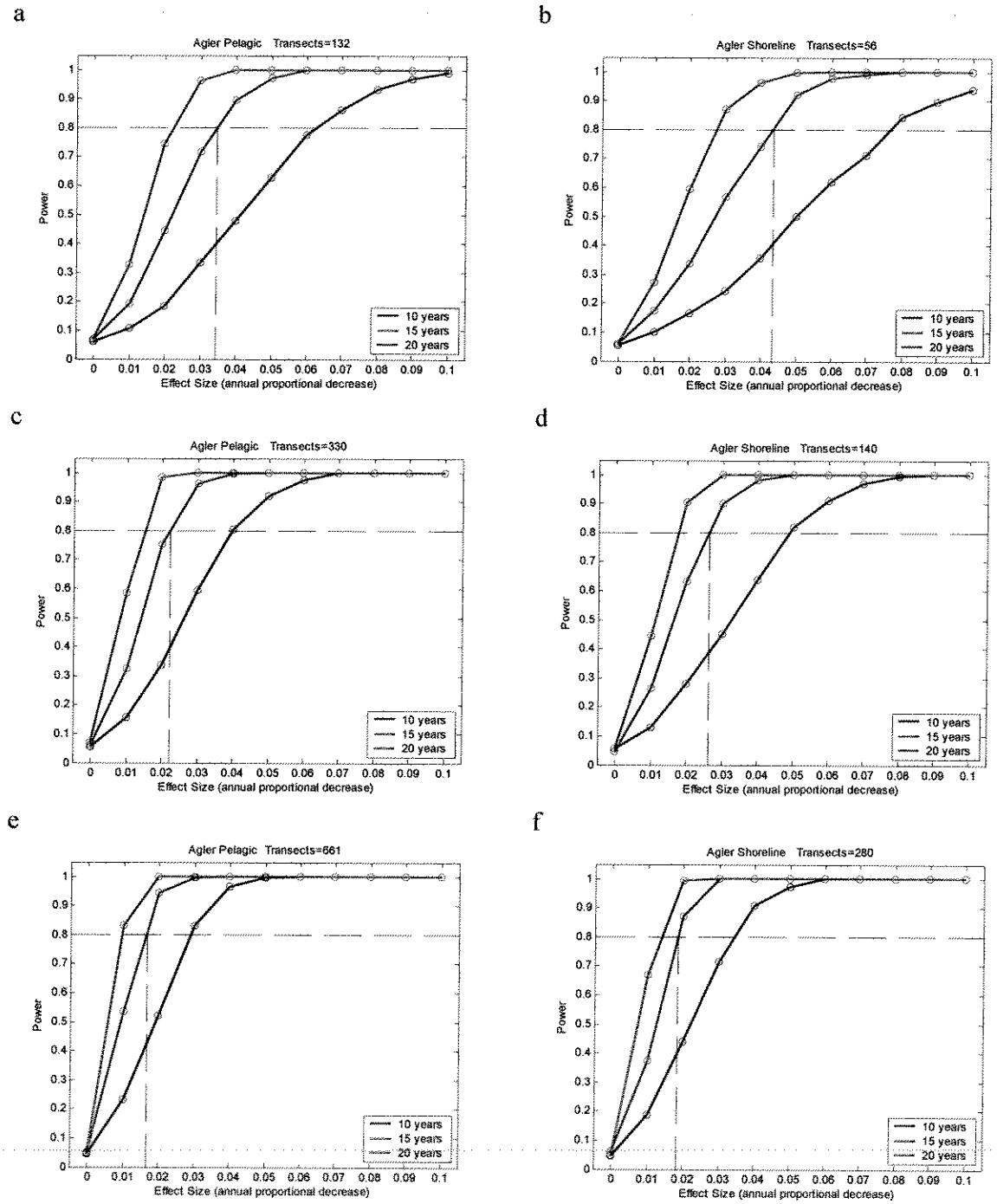

Figure 4. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), based on Agler survey at different levels of survey effort, at $\alpha = 0.05$. Pelagic surveys in left column (a,c,e); shoreline surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

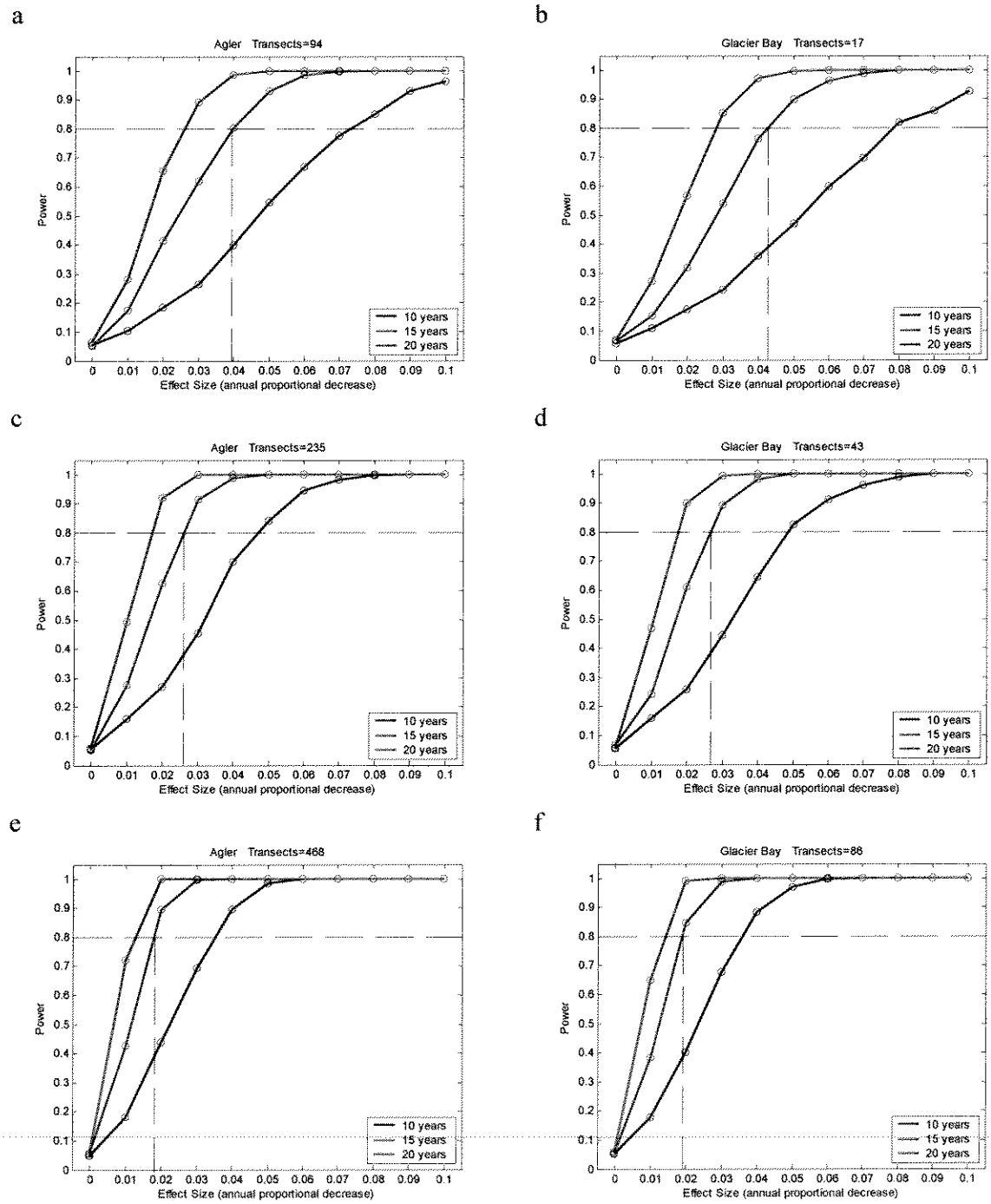

Figure 5. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in Southeast Alaska at different levels of survey effort, at $\alpha = 0.05$. Agler survey (both pelagic and shoreline surveys) in left column (a,c,e); Glacier Bay survey in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

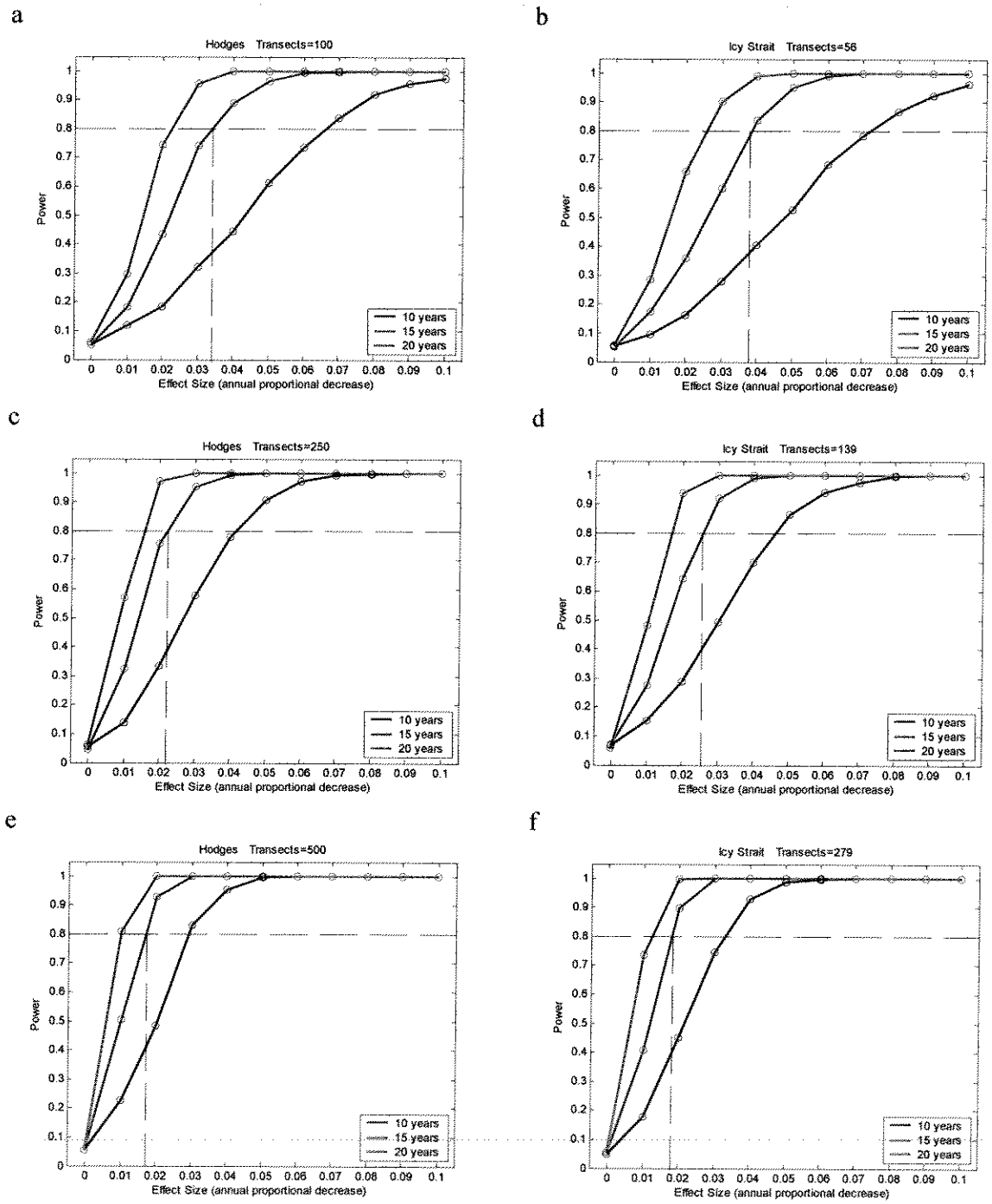

Figure 6. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in Southeast Alaska at different levels of survey effort, at $\alpha = 0.05$. Hodges surveys in left column (a,c,e); Icy Strait surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

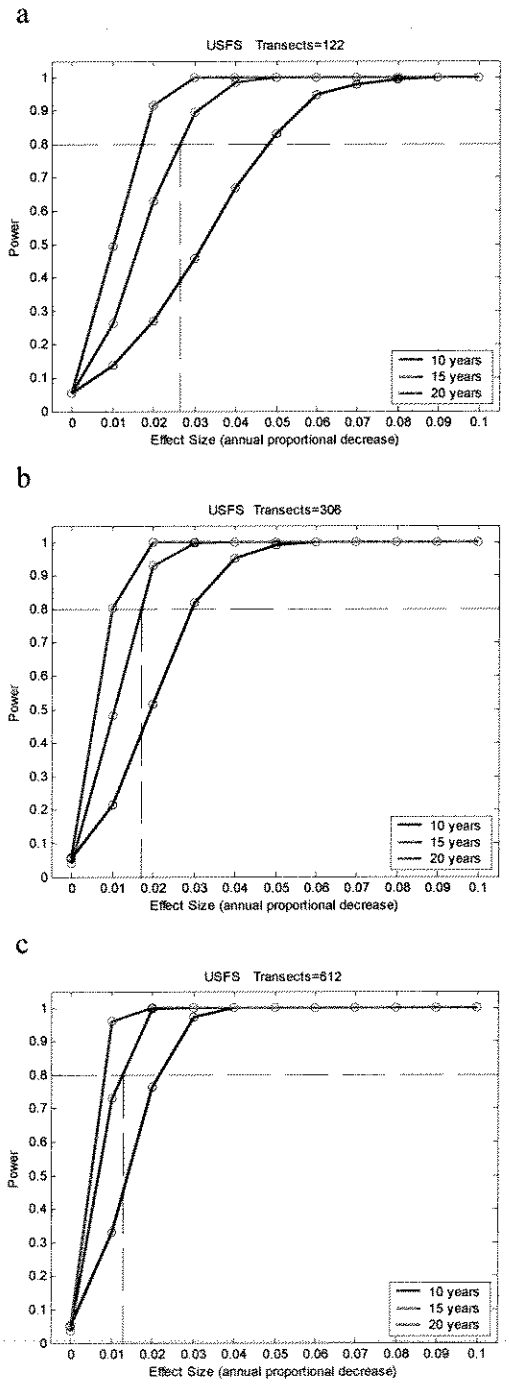

Figure 7. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), for USFS survey in Southeast Alaska at different levels of survey effort, at $\alpha = 0.05$. Effort represented by: (a) 44 km^2; (b) 110 km^2; (c) 220 km^2.

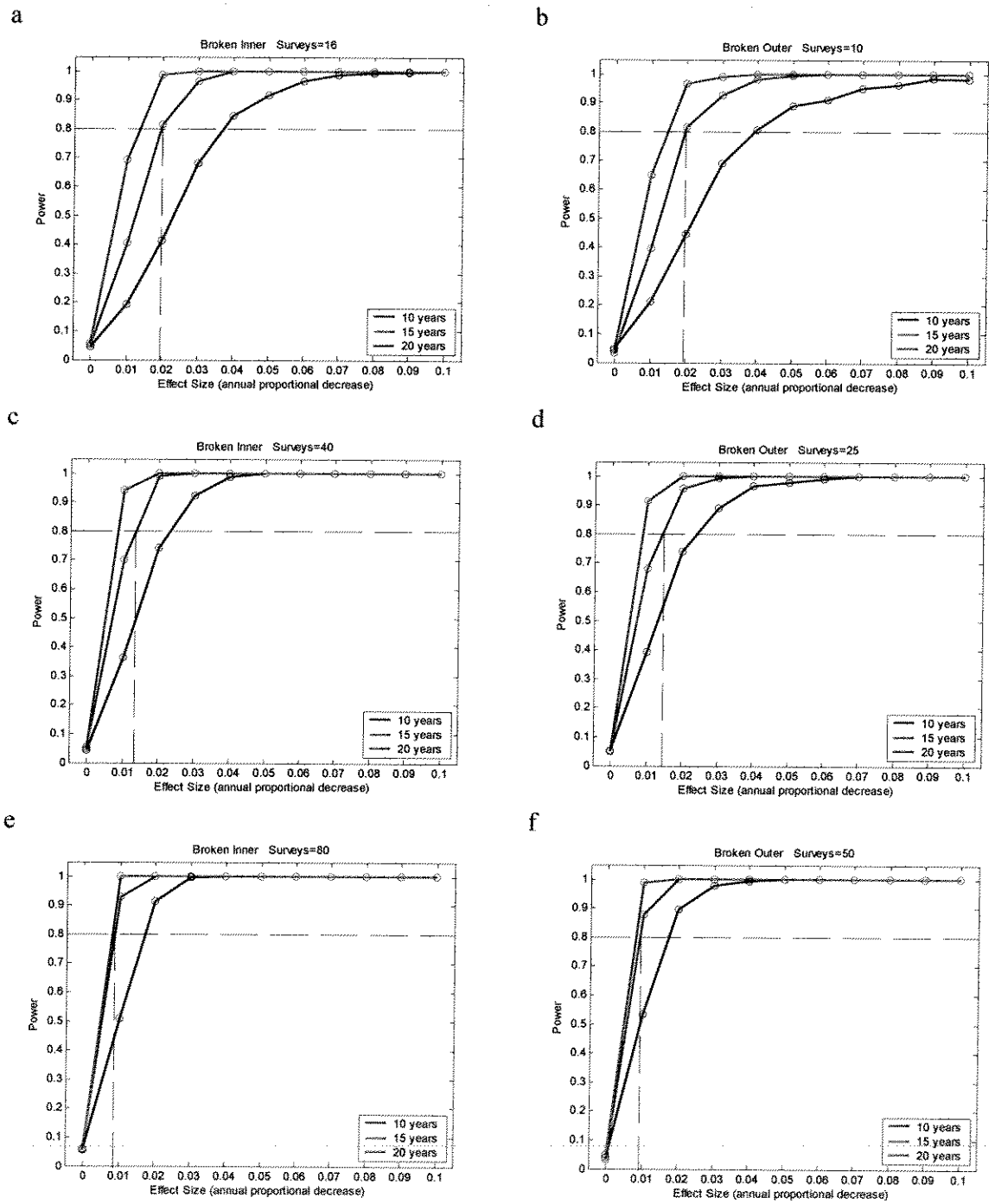

Figure 8. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in British Columbia at different levels of survey effort, at $\alpha = 0.05$. Broken Inner surveys in left column (a,c,e); Broken Outer surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

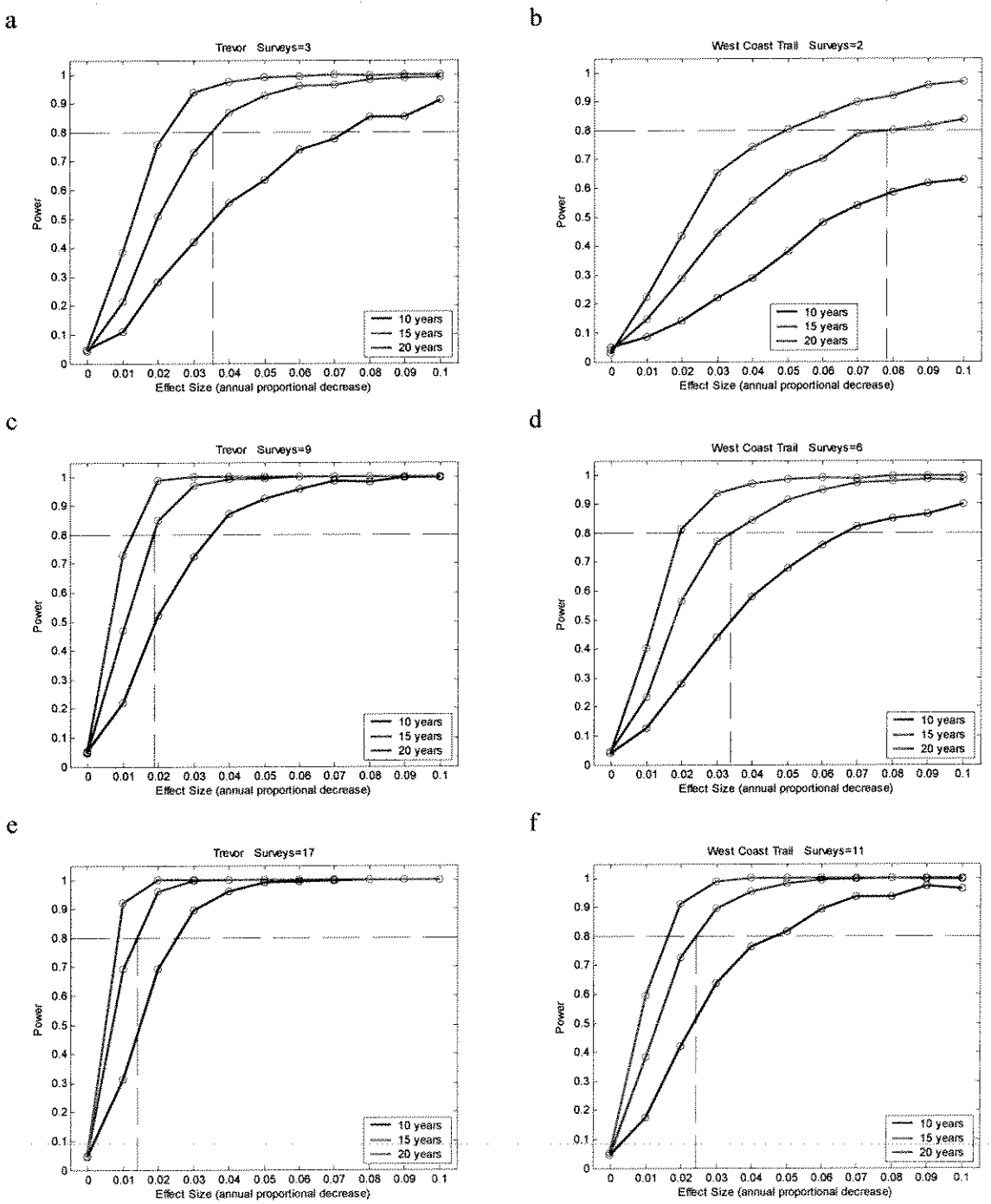

Figure 9. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in British Columbia at different levels of survey effort, at $\alpha = 0.05$. Trevor surveys in left column (a,c,e); West Coast Trail surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

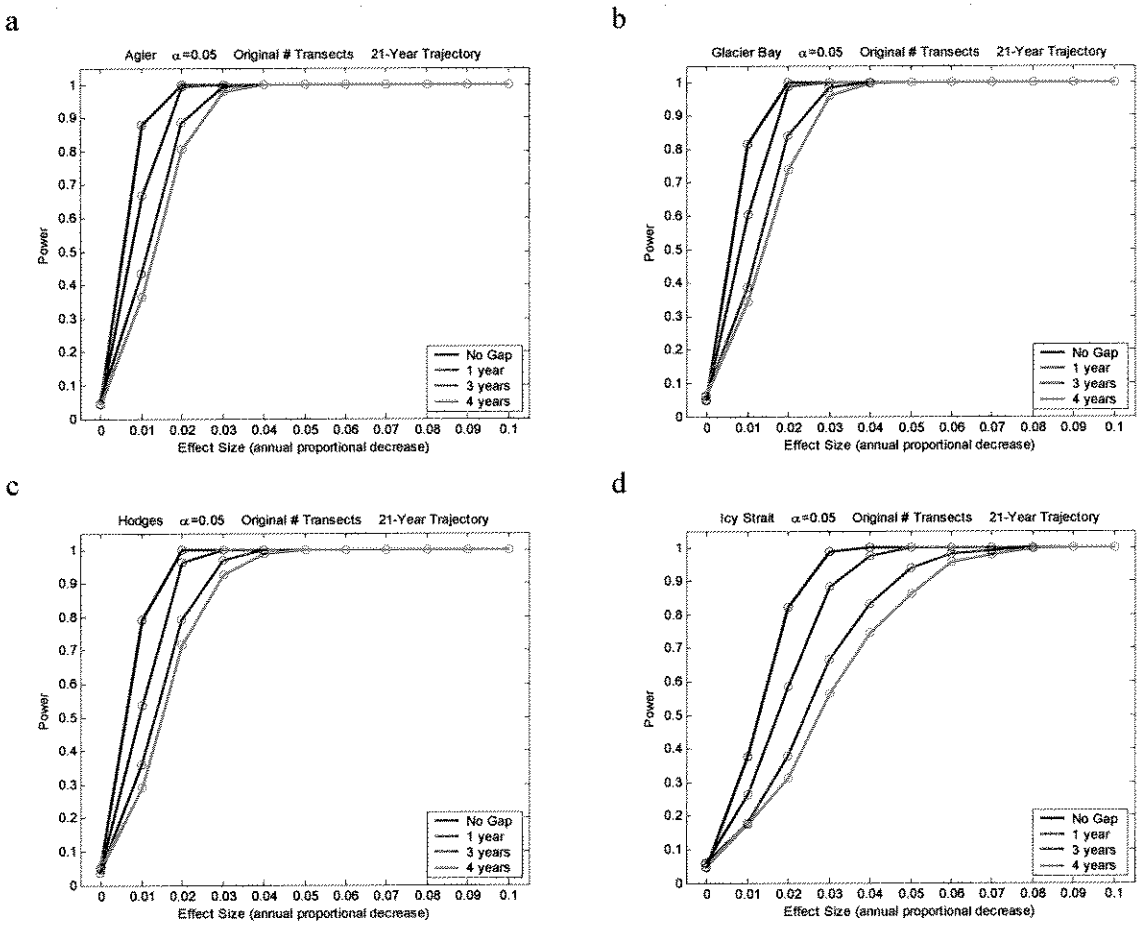

Figure 10. Effect of different periodic sampling schedules on power to detect trend in a 21-year trajectory at $\alpha = 0.05$. Skipping 1 year = sampling every other year, skipping 3 years = sampling every 4th year, etc. Agler (a), Glacier Bay (b), Hodges (c) Icy Strait (d). The blue line in each panel represents annual sampling ("no gap") and, thus, is similar to the red lines representing 20-year trajectories in Figure 2.

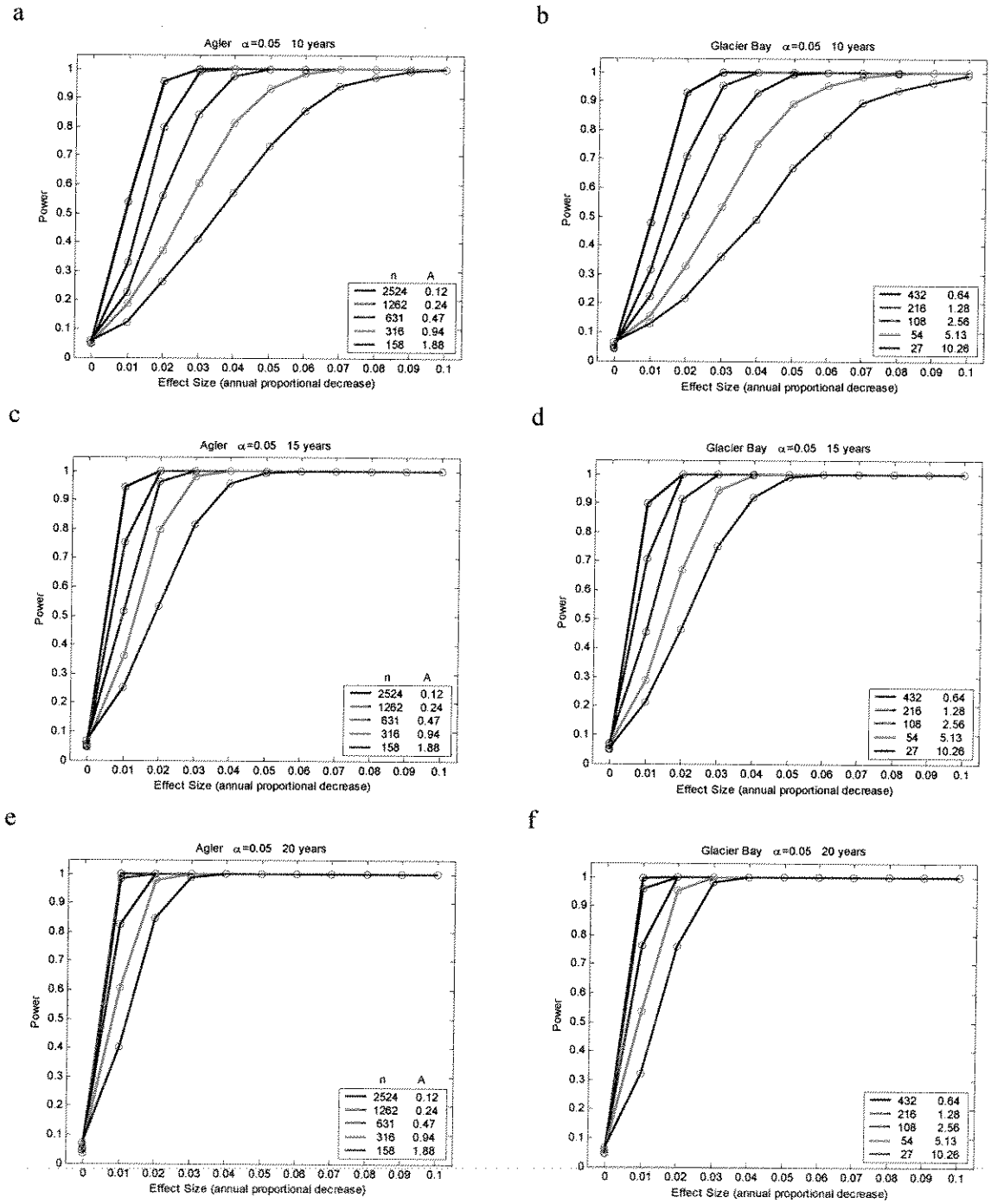

Figure 11. Power to detect trend with constant effort (total transect area), but varying number of transects (*n*, panel legends) and area (km^2) of individual transects (*A*, panel legends). Agler in left column (a,c,e), Glacier Bay in right column (b,d,f). Time trajectories of 10 years in first row (a,b), 15 years (c,d), and 20 years (e,f). Red lines correspond approximately to original number and size of transects. Increasing transect number (decreasing area) represented by green and blue lines; decreasing transect number (increasing area) represented by cyan and magenta lines.

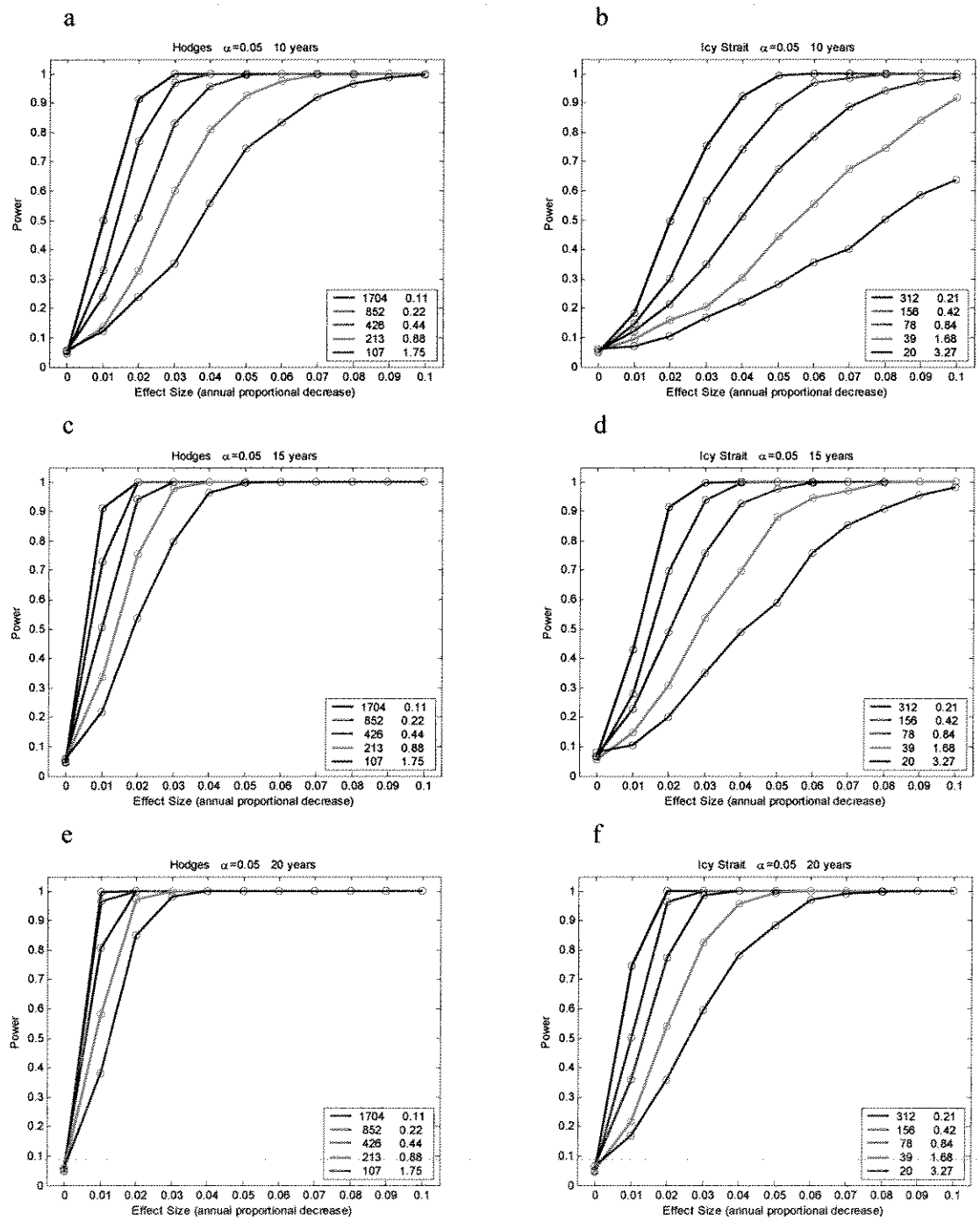

Figure 12. Power to detect trend with constant effort (total transect area), but varying number of transects (*n*, panel legends) and area (km^2) of individual transects (*A*, panel legends). Hodges in left column (a,c,e), Icy Strait in right column (b,d,f). Otherwise as in Figure 11.

Appendix 1. Prepared by John Piatt, Kirsten Bixler and Julia Parrish

Appendix 1. Basic Attributes of Methods for At-Sea Surveys for Marbled Murrelets

		Survey	Agler	Hodges	USFS Nearshore Surveys	Lindell-Icy Strait	USGS-Icy Strait	USFSW-Glacier Bay	Lindell-Glacier Bay	USGS-Glacier Bay	Northwest Forest Plan	Trevor Channel - grid	Trevor Channel - transect	Broken Group Islands, In	West Coast Trail	Tofino and Flores	RIC 2001	Gould and Forsell 1989	Ballance
Transect definition	**Transect Type**	Strip transect	X	X	X	X	X	X	X	X			X	X	X	X		X	X
		Grid transect										X							
		Line transect (record distance, bearing to each bird; est. birds/km2)			X						X						X[3]		
	Data Collection Interval	Discrete (e.g., 10 min count, 6.2 km shoreline transect)	X		X	X		?	X			X	X	X	X	X	X	X	
		Continuous (every observation logged with time/position)		X			X	?		X	X								X
	Transect Length	Fixed distance (e.g., 5 km)			X						X	X	X					X	
		Irregular (e.g., shoreline transects, continuous transects)	X	X		X	X	X	X	X	X			X	X	X	X		X
	Transect Width	No fixed width, usually set by visibility, and species dependent									X						X		X
		Fixed but adjusted to obervation platform (e.g., 300m, 450m, 600m)					X			X									
		Fixed (e.g. 300 m to one side)	X	X	X	X		X	X			X	X[2]	X[2]	X[2]	X		X	
	Distance of Boat from Shore	Fixed (e.g. 100m from shore)	X	X	X			X		?					X				
		Variable (e.g. zigzag, parallel to shore but at multiple distances)	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X
	Forward View Field	Fixed (e.g. ≤ 300 m forward, arc back to 90° abeam of vessel)	X	?	X	X		X	X				X	X	X	X			X
		Fixed but adjusted to obervation platform (e.g., 300m, 450m, 600m)					X			X									
		Forward to end of transect or quadrat									X	X					X		
	Survey Speed	Consistent (e.g. 8-15 knots)				X	X	?	X	?	X							X	
		Variable (e.g., vessel slowed or stop to identify, count birds)	X[1]	X	X			?		?			X	X	X	X	X		
		unknown										X							X
	Transect Location	Randomly selected	X								X								
		Subjectively selected		X	X	X	X	X	X	X		X	X	X	X	X	X	X	
Bird observations	**Birds on water**	Count all birds on water	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Flying birds	Count all flying birds continuously	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
		Count 'traveling' birds during scan only																X	
		Record bearing, flight direction of traveling birds									X						X		X

[1] This assume that Agler followed the Migratory Bird Management (MBM) protocol.

[2] A few early transects may have had a strip width of 200m on either side of the vessel.

[3] Methods include suggestion to include a strip transect (50m either side of boat) to make comparable to previous years of data

[4] Five supplemental standardized techniques when strip transects not possible: skiff counts, coastline counts, ship-follower counts, station counts, general observations

Appendix 2. Details and Review of Methods for At-Sea Marbled Murrelet Surveys Prepared by John Piatt, Kirsten Bixler and Julia Parrish

Introduction

In Alaska, surveys for marine birds generally employ strip-transect methods, whereby all birds observed within a fixed-width strip (e.g., 200–300 m) around a moving vessel are recorded (Gould and Forsell, 1989; Klosiewski and Laing, 1994). In Washington, Oregon, and California, murrelets are now usually counted using line-transect methods without fixed widths, and the distance to every bird also is recorded so that detection functions may be calculated to adjust for conservative negative bias (under estimate) due to the drop-off in visibility of birds with distance (Bentivoglio et al., 2002). This method has not been adopted in Alaska yet, in part because of concerns about comparability with historical data and because it might be difficult to collect line-distance data on the large number of murrelets and other species typically found in Alaska during summer. In any case, small boat surveys in Alaska generally employ 200-m strip widths (Agler et al., 1998), i.e., 100 m to either side of the vessel. There is a small conservative bias in strip-transect methods (Klosiewski and Laing, 1994), where most murrelets (and other species) observed out to the full 100 m are counted. The bias is likely to be consistent over time (Evans Mack et al., 2002), but contributes to conservative, underestimates of the population size (see below).

In British Columbia, population trends of Marbled Murrelets have been assessed from repeated surveys made at-sea during the breeding season (late April–mid-July). Data are available from six transect routes which have been repeatedly sampled (but not in every year) within the period 1979 to 2006, and two routes sampled in 1996–2000. Most of the data cover the years 1995–2006. Seven of the transects were off southwest Vancouver Island (Clayoquot and Barkley Sounds, and the West Coast Trail) and one was in Laskeek Bay off Haida Gwaii (Queen Charlotte Islands). Methods varied somewhat among the studies but generally murrelets were counted on both sides of a small vessel

running at constant speed along a fixed route, and densities were estimated either using an unlimited distance line-transect (giving densities as birds per km) or within 300 m-wide strip-transects (giving densities as birds per km2)..

Alaska

Southeast Alaska hosts the largest concentration of Marbled Murrelets (*Brachyramphus marmoratus*) found anywhere throughout their range from California to the Bering Sea (Piatt and Naslund, 1995; Nelson, 1997). A regional-scale survey of Southeast Alaska in 1994 suggested that between 486,000 and 888,000 *Brachyramphus* murrelets resided in Southeast Alaska during summer (Agler et al., 1998). This survey has not been repeated, and we do not know the size of the present-day murrelet population in Southeast Alaska. However, Piatt et al. (2006) compiled and analyzed boat-based survey data from several locations and compared them with the previous surveys conducted by Agler, Lindell et al.. These data suggest a decline in murrelet populations during the short period between surveys. Estimated populations may have diminished by about 45% and at an approximate overall rate of -11.5 percent per year. Owing to differences in timing and methodology between surveys, these estimated changes should be considered tentative and part of the overall assessment of populations in Southeast Alaska.

Surveys of Southeast Alaska

Agler Survey Methods

A regional-scale small boat survey of Southeast Alaska was completed in 1994 (Agler et al., 1998). These methods were originally developed in 1989 by S. Klowsiswoki for the US Fish and Wildlife Service, Migratory Bird Management, and have been widely used and reported in detail elsewhere (e.g., Klowieski and Laing, 1994; Agler et al., 1998, 1999; Irons et al., 2000). In summary, 631 randomly selected transects (see Piatt et al., 2007, Figure F1) were surveyed between June 9 and July 27, 1994. We compiled the original data from this survey from the U.S. Fish and Wildlife Service (Migratory Bird Management, Anchorage).The study area was divided into two strata: (1) coastal (all waters <200 m from shore), and (2) offshore (all waters >200 m from shore). Potential

transects were created by using Geographic Information System (GIS) to overlay a grid of 1.9 km (1 nmi) square blocks over the entire southeast area, and selecting at random from those that had no land closer than 200 m from shore (offshore block) and those that did (coastal block). Transects in offshore blocks simply cut straight through blocks and averaged 1.7 km in length. Coastal transects followed any shoreline falling within the block and averaged 3.9 km in length. When two adjacent blocks were selected, observers paused between transects to increase independence of the samples and to collect environmental data. The survey was completed during all phases of the tidal cycle and to ensure that all *Brachyramphus* murrelets within the transect were seen, wave height during the survey was 0.6m or less. In all transects, two observers surveyed a sampling window 100 m on either side and ahead of the boat. All flying birds and birds on the water were recorded continuously and binoculars were used to aid in identification of species. Because of the difficulty in distinguishing Marbled from Kittlitz's Murrelet, most birds were recorded simply as *Brachyramphus* murrelets. In order to maintain accuracy in distance estimation, observers practiced with duck decoys.

This Migratory Bird Management method for surveying marine birds was used in Prince William Sound (PWS), Lower Cook Inlet (LCI), and in other SE Alaska wide surveys as well. Except for the Prince William Sound shoreline transects, patterned after those developed by Irons, Nysewander, and Trapp (1988), all transects were created using a grid overlaid onto a map of the survey area. The grid blocks were 5 minutes latitude by 5 minutes longitude in PWS, 2 minutes latitude by 4 minutes longitude in LCI, and 2 minutes latitude by 1 minute longitude in SE Alaska. Blocks were selected randomly to be surveyed. In PWS, shoreline transects were located in blocks that contained greater than 1 nmi of shoreline and offshore transects, considered 'coastal/pelagic', were located in blocks that contained less than 1 nmi of shoreline. Coastal/pelagic blocks each contained two transects that ran true north/south and were located within 1 minute of longitude inside both the east and west edge of the block. In SE Alaska and LCI, the shoreline was sampled if the block was selected. If the length of the shore was less than 0.5 miles, it was attached to the following block. Offshore transects, in SE Alaska and LCI were greater than 200m from shore and were considered 'pelagic'. In SE Alaska,

pelagic transects ran east/west on the upper edge of the block and ranged from 1 mile to 0.1 miles long. In LCI, pelagic transects began at the northeast corner of the grid and either ran north/south (all open water transects) or east/west and ranged from 2.49 to 0.5 nmi long. If any transect in LCI was less than 0.5 nmi, it was joined to the following block. If there was overlap between pelagic and shoreline transects, the shoreline data was collected in a separate column.

As mentioned above, the strip width was 100m on either side, ahead of and above the boat. All flying birds and birds on the water were counted and identified to the lowest taxonomic level possible. Care was taken to not count birds more than once. The vessel maintained at a speed of between 5 and 10 knots but could be stopped to identify birds. When the vessel was stopped, no new observations were recorded. During shoreline transects the vessel traveled 100m from shore and one observer surveyed the inside water (100m to 0m from the shore) and the other recorded data and surveyed the outside water (100m to 200m from shore).

Data collected included transect number, subjective observation condition, date, wind speed, wind direction, time, sea state, low tide height and time, high tide height and time, tide state, inside observer, water temperature, air temperature, outside observer, ice type, ice cover, vessel name, human disturbance, oiling conditions, and comments. Bird and mammal observations included the side of the boat (shoreline transects), number of animals, and behavior at first sight (flying, on water, on land, flying in same direction as boat, or sitting on a floating object).

Hodges Survey Methods

Between 1997 and 2001, the U.S. Fish and Wildlife Service conducted small boat surveys over about 16 percent of the shoreline of Southeast Alaska in order to provide correction factors for numbers of birds observed on aerial surveys (Jack Hodges and Debbie Groves, U.S. Fish and Wildlife Service, Migratory Bird Management, Juneau Field Office, unpub. data, 1997–2001). Areas for at-sea surveys were subjectively selected to be logistically practical and representative of all habitat types. Boat surveys were conducted over a 5-

year period, with similar effort in each of 4 of those years (1997: 1,015 km; 1998: 743 km; 1999: 705 km; 2001: 894 km). Effort was distributed over a different geographic range of Southeast Alaska in each year. On boat surveys, two observers with binoculars rode in stable skiffs with outboard motors. Skiffs were driven about 100 m from shore and all birds observed between the boat and shore were counted. On the offshore side of the boat, birds were surveyed out to 300 m. All marine birds flying or on the water within the transect zone were identified and counted on boat surveys. Data were collected continuously over stretches of shoreline, and not binned into transects. Laptop computers, housed in protected cases, allowed Global Positioning System (GPS) locations to be tagged with each observation. Because the purpose of the boat surveys was to provide a correction factor for aerial surveys, the vessel was slowed or stopped when necessary in order to count flocks or identify species. The evasive behavior of birds ahead of the boat was carefully monitored and the path of the skiff adjusted to help prevent roll up of flocks ahead of the skiff that might have resulted in double counting.

The skiffs were driven in a similar fashion as the airplane track, that is, distance from shore was optimized to best census coastal birds such as harlequin ducks (*Histrionicus histrionicus*), mergansers and gulls. Murrelets can be observed as much as 1 km from shore under optimum conditions (Speckman et al., 2000). In field trials, observers traveling in small skiffs detected 60–80 percent of murrelets at distances of as much as 200 m even when the water surface was choppy (Mack et al., 2002). However, we assume that under average conditions, counts of murrelets beyond 100 m from the boat were biased low because some individuals were not detected (Ralph and Miller, 1995; Strong et al., 1995), but most murrelets as much as 100 m distance were detected—which is why this distance is frequently used as a truncation distance on line transects for murrelets (Bentivoglio et al., 2002). Therefore, to be conservative in comparisons to the Agler data, and to keep these transect tracks comparable to others conducted by USFWS, we assume an effective transect width of 200 m (100 m either side of boat) for Marbled Murrelets and we use this distance in all calculations of density. Correspondingly, all density and population estimates from Hodges' shoreline survey probably are biased upwards because the counts included individuals detected at greater than 100 m. These

surveys were never intended to collect population assessment data for Marbled Murrelets and observers are not confident that they observed all murrelets on boat-based surveys (J. Hodges, U.S. Fish and Wildlife Service, oral commun., 2006). We compared estimates of murrelet densities with those of other seabird species observed on both Agler and Hodges surveys to get some idea of the magnitude of errors arising from the use of different methods among surveys.

All of Hodge's boat surveys were conducted between August 1–13 over all years (1997–2001), and this constitutes another source of error in the data. Bird numbers observed in early August tend to be elevated by ca. 20–40 percent relative to counts earlier in the season (DeGange, 1996; Speckman et al., 2000; Kuletz, 2005). This corresponds to the late chick-rearing and fledging period when foraging adults are highly mobile (Whitworth et al., 2000), and large numbers of failed breeders and subadults contribute to the size of local populations in the surveyed area (Speckman et al., 2000). For these reasons, we assume that counts of murrelets on the 1997–2001 boat-based shoreline surveys would be biased high relative to counts conducted in June and July (Speckman et al., 2000), and hence conservative when compared to the Agler surveys that were conducted during June and July 1994. No adjustments were made for this potential source of error.

US Forest Service Survey Methods

Between 1991 and 1995, the United States Forest Service surveyed nearshore waters in Southeast Alaska in Craig, Thorne Bay, Hoonah, Juneau, Admiralty, Ketchikan-Misty Fjords, Petersburg, Sitka, Wrangell and Yakutat Ranger Districts for Marbled Murrelets, as well as other marine birds and mammals. These surveys more or less followed one protocol, Methods for Surveys in Southeast Alaska of Seabirds and Mammals in Nearshore Waters: A Guide, by C.J. Ralph and S.L. Miller, 1991.The protocol combines attributes of both strip-transects and line-transects. The focus of observation was within 100 meters of either side of the boat forming a 200m wide strip. This approach adheres to a standard strip-transect survey although sightings outside of the strip were recorded as also as time allowed. As in standard line-transect surveys, observers recorded the distance

of the animal(s) perpendicular to the path of the vessel. All birds that were actively foraging or appeared to be searching for food in flight were recorded. All birds on the water and flying birds that were not foraging were always recorded within the 200m strip, and outside 200m as time permitted. Birds following the vessel were recorded once per segment. The average distance of the birds was recorded unless the flock stretched to both sides of the boat. Observations included age, plumage, and location (side of boat). Terrestrial birds and mammals could be counted if within 100m of the shoreline.

The observer(s), standing in the front of the boat with an unobstructed view, scanned a 180° arc, as far as 100m from the boat, (from beam, to bow, to beam). A scan was completed every 3 to 4 seconds. The driver observed as well, particularly for birds flushing ahead of the boat. Binoculars were used to aid in identification of species. Boat speed was 8 to 12 knots, with the maximum speed in flat calm weather when birds were most visible. The boat could be stopped briefly to identify a birds or to determine the species composition and size of a large flock. Birds that otherwise would not have been seen and any flying birds were not counted, while the boat was stopped. To retain accuracy in distance estimation, a buoy was towed on 100m of line behind the boat for the first 4 km and again after every 20 km. Environmental data included wave height, whitecap density, tide, water temperature, visibility, precipitation, and cloud cover. All data was originally recorded using a tape recorder and later transcribed to standardized data sheets.

Transects were divided into 2 km segments (1.08 nautical miles) when along the shore and 0.2 km segments when perpendicular to shore. The final segment in a transect around an island was only included if between 1.8 and 2.2 km in length. Transects followed the curvature of the coastline, entering coves and inlets if more than 250m wide and generally followed depth contours. There are two types of survey transects described in the protocol: 1) intensive transects, designed to expose daily and seasonal murrelet movements, and 2) extensive transects, designed to assess the population size of murrelets in an area.

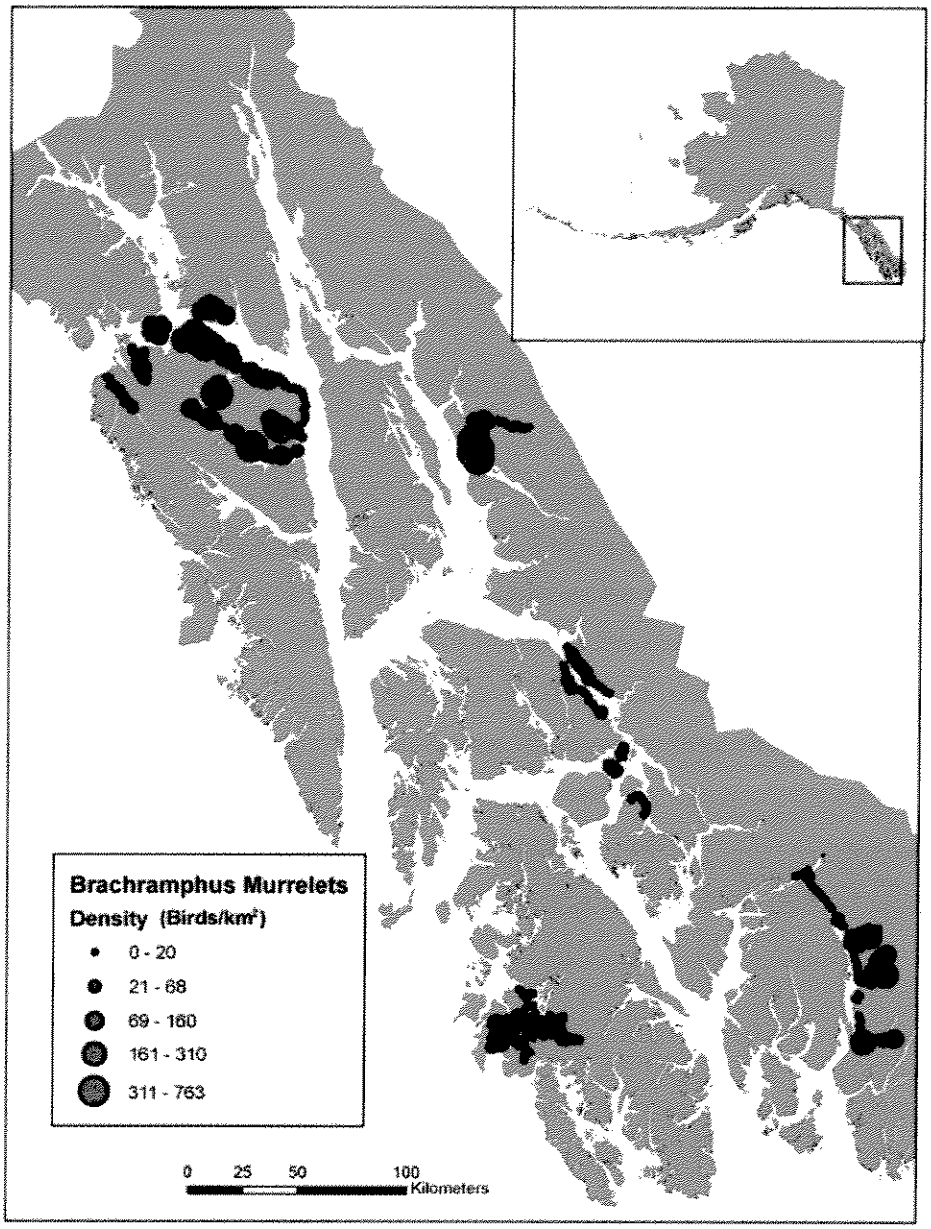

Figure 1. Surveys conducted by USFS in 1991 and 1992, and included in power analysis for this report.

Extensive transects were composed of 2 km long segments parallel to the shoreline (Figure 1 above), at both 100 m and 500 m from shore. Every 4 km (two segments) at 100 m from shore, a perpendicular segment was completed consisting of three legs in

each of three different directions: 1) perpendicular to the shore beginning at 100 m from shore and extending to 3,000 m from the shoreline or to the center of the waterway, 2) parallel to shore for 500m, and 3) perpendicular to the shore, back to 100 m from the shoreline. Perpendicular segments were at least 3 km apart and were omitted if they overlapped segments from neighboring shores. They were split into 0.2km segments. Intensive transects were composed of 2 km long segments parallel to the shoreline at each of five distances from shore; 100 m, 500 m, 1000 m, 1500 m and 2000 m. The vessel followed a U-shaped course between segments at different distances from shore so the transects at each distance from shore were surveyed in the opposite direction from the previous distance from shore. Intensive transects were completed repeatedly through the year.

Surveys of Icy Strait

Lindell Survey Methods

Beginning in 1993, the U.S. Fish and Wildlife Service initiated a systematic survey of Icy Strait (Lindell, 2005), an important staging and foraging area for thousands of murrelets in northern Southeast Alaska (DeGange, 1996; Whitworth et al., 2000). The survey was comprised of a grid of 12 north-south legs separated by 2.5 nmi and set perpendicular to Icy Strait, running from the head of Chatham Strait in the east to the mouth of Glacier Bay in the west (see Piatt et al., 2007, Figure G2). The cross-strait transects were joined by 13 east-west legs that ran parallel to the coast on both sides of Icy Strait. The total distance surveyed comprised 240 km or about 70 km^2 within an area of about 1,000 km^2. This grid was surveyed repeatedly within and between the years of 1993 to 1999 by Lindell (2005) and then once a year between 1999 and 2003 by the U.S. Geological Survey (Robards et al., 2003). The end of each Icy Strait segment was fixed with latitude and longitude waypoints, and these were used by Lindell (2005) as start and stop positions for each segment of the Icy Strait survey. Near-shore segments were placed as near as possible to the adjacent shore without compromising survey vessel safety. These along-shore segments were straight-line transects and did not often venture within 200 m of shore. In this respect, they differ from small-boat protocols used by other researchers (Agler et al., 1998) where vessels closely followed shorelines at 100 m distance offshore,

and where offshore (≥ 200 m) areas were segregated as different strata for statistical analysis.

Lindell (2005) used shipboard survey methods described by Gould and Forsell (1989), with the exception that all flying birds were counted continuously (per Klosiewski and Laing, 1994) rather than on periodic scans. All surveys were completed using the U.S. Fish and Wildlife Service motor vessel *M/V Curlew*, a 65-foot ship, at a cruising speed of about 10 knots. Observers were stationed approximately 5 meters above the water surface atop the ship's wheelhouse. At least two observers were on duty during all surveys. A third observer was added when large numbers of birds were encountered. They identified and recorded all birds and mammals encountered within 150 m either side, behind, and ahead of the survey vessel. Observers estimated this distance using sight boards installed on the vessel and by calibrating against duck decoys or similarly sized buoys placed at a known distance from the vessel. Observers sampled continuously along transects, and binoculars were used to aid in identification of species. Surveys typically were conducted when wave heights were less than 0.6 m, with few, if any, white caps. Surveys were conducted during all phases of the tide and throughout daylight hours, which would tend to reduce the variability associated with those factors (Speckman et al., 2000). Observers recorded the time of each *Brachyramphus* murrelet observation by hour and minute. Positions for each minute were calculated from time between waypoints obtained from the Differential Global Positioning System.

Lindell (2005) conducted 15 complete surveys of Icy Strait during the summers of 1993–99. In some years, he replicated surveys in June, July, and August. Bird numbers observed in early August tended to be elevated and more variable (DeGange, 1996). This corresponds to the late chick-rearing period when foraging adults are highly mobile (Whitworth et al., 2000), and large numbers of failed breeders and subadults also contribute to volatility in size of local populations (Speckman et al., 2000). For all these reasons, then, we excluded all of Lindell's surveys that were conducted in the month of August, leaving seven surveys that were conducted between June 14 and July 16, in 1993, 1995, 1998, and 1999.

USGS Survey Methods

Surveys were conducted by USGS in Icy Strait, beginning in 1999, using the same protocols as Lindell (Gould and Forsell, 1989). Again, all flying birds were counted continuously (e.g., Agler et al., 1998) rather than on periodic scans. Exactly the same waypoints and segments of Lindell surveys were used. In 1999, surveys were conducted using a 300 m strip transect, counting birds on 150 m either side of the *R/V Pandalus*, (22 m length, 5 m viewing height). In 2000–03, observations were made from several vessels including the *R/V Alaskan Gyre* (17 m length, 5 m viewing height, 300 m transect width) and the smaller vessels *Lutris II*, (8 m, 2 m viewing height) and *David Grey* (10 m, 2.5 m viewing height) from which we reduced the strip width from 300 to 200 m. Although the total linear distance surveyed (240 km) did not change among years, the total area surveyed changed from about 72 km2 during 1993–99 to about 52 km2 during 2000–03 because of the difference in vessel type and strip widths. Other USGS methods were similar to those used by Lindell and described above.

Birds were identified to species whenever possible, and only 19 Kittlitz's were observed out of 2,188 birds identified, so we are essentially analyzing trends for Marbled Murrelets in this report. All surveys were conducted between June 11 and June 23, so seasonal variability is not a significant issue. Surveys were not conducted when seas exceeded 1 m. Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (Glenn Ford, R.G. Ford Consulting Inc.) that plots sighting positions continuously using Global Positioning System (GPS) coordinates. GPS locations were obtained from a Rockwell Precision Lightweight Global-Positioning Receiver (PLGR). PLGR units have a worst-case horizontal position accuracy of ±10 m at speeds less than 36 kph.

Surveys of Glacier Bay

Glacier Bay, a large protected body of water located in northern Southeast Alaska, was surveyed for marine birds in 1991 (Piatt et al. 1991), 1993 (Lindell, 2005) and in 1999–2003 (Robards et al., 2003).

Drew et al. (U.S. Geological Survey, unpub. data, 2006). The design of surveys varied considerably among years. The 1991 survey was designed to sample shoreline habitat, and only about 10 percent of transects sampled offshore habitat haphazardly. In contrast, the survey conducted in 1993 sampled mostly offshore waters, and ventured near shore only near the end of pelagic transects or when surveying long, narrow arms of Glacier Bay. Finally, the 1999–2003 surveys sampled both shoreline and offshore habitats extensively, with about 35 percent of effort directed to offshore habitat.

U.S. Fish and Wildlife Service Survey Methods

In 1991, biologists with the U.S. Fish and Wildlife Service, Glacier Bay National Park and University of Alaska, Fairbanks, conducted a systematic survey of Glacier Bay Alaska (Piatt et al., 1991). The purpose of these surveys was to conduct a preliminary reconnaissance for both Marbled and Kittlitz's Murrelets in Glacier Bay, as well as to collect baseline data on other marine bird and mammal species in the park. Using small, open skiffs, observers set out to survey the entire coastline and opportunistically sampled 15 offshore segments as well (see Piatt et al., 2007, Figure H2). Transect lengths ranged from 0.88 to 11.98 km with a total length of 723.36 km (see Piatt et al., 2007, table H1) and a surveyed area of 144.76 km2 (about 10 percent of which was offshore).

Observers used standard sampling protocols developed for small-boat surveys of Prince William Sound shoreline following the *Exxon Valdez* oil spill (Klowsiewski and Laing, 1994). All flying birds were counted continuously (e.g., Agler et al., 1998) rather than on periodic scans (Gould and Forsell, 1989). Observers viewed birds from about 2 m above the water surface and two observers were on duty during all surveys. Observers surveyed continuously along transects and binoculars were used to aid in identification of species. All swimming birds and mammals within 100 m on either side or 200 m forward of the boat were identified to species. For more details on methods, see Klosiewski and Laing, 1994; Agler et al., 1998, 1999; Robards et al., 2003).

Lindell Survey Methods

In 1993, the U.S. Fish and Wildlife Service conducted systematic surveys of Glacier Bay, Alaska (Lindell, 2005). The survey consisted of 38 strip transects laid out in a zig-zag fashion to broadly cover the full length of Glacier Bay (see Piatt et al., Figure H3). Transect lengths ranged from 1.4 to 14.35 km with a total length of 278.6 km and a surveyed area of 83.6 km2 (see Piatt et al., table H1). Surveys were conducted using the U.S. Fish and Wildlife Service motor vessel *Curlew*, a 65-foot ship. The survey was conducted once in June 1993 and replicated later in mid-August 1993. However, surveys for murrelets in late July and August may detect higher densities and greater variability within and between years (DeGange, 1996; Speckman et al., 2000). This corresponds to the late chick-rearing period when foraging adults are highly mobile (Speckman et al., 2000; Whitworth et al., 2000), and large numbers of failed breeders and subadults also contribute to the size and volatility of local populations (Speckman et al., 2000). For these reasons, the best time period for monitoring population change in murrelets is during June and early July when adults are still tied to nesting areas and attendance at sea is most stable (Speckman et al., 2000). Because of this, and because all other survey data were collected in June or early July, we excluded Lindell's survey data from August (even though murrelet densities [31.0 birds per square kilometer] were similar to those observed in June). Lindell (2005) used shipboard survey methods described by Gould and Forsell (1989), with the exception that all flying birds were counted continuously (per Klosiewski and Laing, 1994) rather than on periodic scans. All surveys were completed using the *M/V Curlew* at a cruising speed of about 10 nmi/h (knots) (18.5 km/h). Observers were stationed approximately 5 meters above the water surface atop the ship's wheel house.

At least two observers were on duty during all surveys. A third observer was added when large numbers of birds were encountered. They identified and recorded all birds and mammals encountered within 150 m either side and ahead of the survey vessel. Observers estimated this distance using sight boards installed on the vessel and by calibrating against duck decoys or similarly sized buoys placed at a known distance from the vessel. Observers sampled continuously along transects, and binoculars were used to aid in

identification of species. Surveys typically were conducted when wave heights were less than 0.6 m (2 ft), with few, if any, white caps. Surveys were conducted during all phases of the tide and throughout daylight hours, which would tend to reduce the variability associated with those factors (Speckman et al., 2000). Observers recorded the time of each *Brachyramphus* murrelet observation by hour and minute. Positions for each minute were calculated from time between waypoints obtained from the Differential Global Positioning System.

USGS Survey Methods

Beginning in 1999, U.S. Geological Survey (USGS) biologists collected data along the entire coastline of Glacier Bay and on offshore transects that were perpendicular to the coastline and spaced at 2.5 nmi intervals (see Piatt et al., 2007, Figure H4). Methodologies were those recommended in Gould and Forsell (1989) for ship-based surveys except that all flying birds were counted continuously in order to be comparable with previous surveys of Glacier Bay (Piatt et al., 1991; Lindell, 2005). Transect lengths varied from 1.2 to 12.7 km with a total length of more than 1,100 km and a surveyed area of more than 250 km2 each year (see Piatt et al., 2007, table H1), about 35 percent of which was offshore habitat.

During the years of study (1999–2003), several vessels were used to collect survey data. Observers on the *R/V Pandalus* (22 m length, 5-m viewing height, 300-m transect width) and Alaskan Gyre *R/V Alaskan Gyre* (17 m, 5-m viewing height, 300-m transect width) counted and identified birds and mammals within 150 m on either side or 150 m forward of the boat. Several smaller vessels also were used in these surveys. Due to the lower viewing angles from these boats, we limited the transect window to 100 m on either side and 100 m forward of the boats *Lutris II*, (8 m, 2-m viewing height), *David Grey* (10 m, 2.5-m viewing height), *Capelin* (8 m, 2.5-m viewing height), and *Sigma-t* (9.5 m, 2-m viewing height). Observers actively scanned ahead of and alongside the survey vessel, and species identifications were confirmed using 7–10 power binoculars. Standard guides were used for identifications. All Marbled, Kittlitz's and Unidentified Murrelets were combined as *Brachyramphus* murrelets.

All surveys were conducted between June 11 and June 23, so seasonal variability is not an issue. Surveys were not conducted when seas exceeded 1 m. Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (DLOG; Glenn Ford, ECI) that plots sighting positions continuously using Global Positioning System (GPS) coordinates. GPS locations were obtained from a Rockwell Precision Lightweight Global-Positioning Receiver (PLGR). PLGR units have a worst-case horizontal position accuracy of ± 10 m at speeds less than 36 kph. Data were collected and organized at spatial scales ranging between about 1–14 km in length and transects averaged about 4–10 km in length on all surveys.

Washington, Oregon and California

Northwest Forest Plan Survey Methods

From 2000 to the present, at-sea surveys for Marbled Murrelets in Washington, Oregon, and California were completed using standardized methods developed by the Marbled Murrelet Effectiveness Monitoring Program of the Northwest Forest Plan (Bentivoglio et al. 2002; Miller et al. 2005; Lance and Pearson, 2005). The area surveyed included 5 conservation zones between the Canadian border and San Francisco Bay (Miller et al. 2005). Each zone was split into strata based upon differences in geography and murrelet density. Strata were further divided into primary sampling units (PSUs), areas essentially rectangular in shape, 20km long, parallel to the shoreline, and variable in width. Each PSU inshore boundary was located at the minimum distance from shore allowing safe travel. The offshore boundary location (≤8km from shore) was chosen based upon data on the decline of murrelets as distance from shore increased (see Table 3-1 in Miller et al., 2005). PSUs were separated into inshore and offshore subunits and the location of the centerline between them again depended on the decline of murrelets with distance from shore. Inshore subunits were divided into four 5 km long transects and each transect was split into four bins, parallel to shore and of equal size. 30 PSUs were generally randomly selected for surveys in each conservation zone, although strata with higher densities of murrelets were sampled more often. Once all PSUs were chosen in zones with less than

30 PSUs, they became available again for selection. Exceptions to the above PSU selection process include 1) in Zone 1, with 98 PSUs, the same set are surveyed each year after the initial random selection in 2000, and 2) in Zone 5, stratum 2, four out of the eight PSUs were randomly selected for sampling each year. The inshore unit was sampled parallel to the coastline, and one of the four transects in each PSU was randomly placed in each of the four bins. The offshore subunit of each PSU was surveyed in a zigzag transect for all or a portion of the length of the PSU, and the trajectory was determined by the randomly selected start position. The length of the zigzag transect was determined by a program that optimized the allocation of effort given historic murrelet densities at a given distance from shore. Approximately 160 PSUs were sampled each year, although in some years weather precluded sampling of a few PSUs. Surveys were discontinued if the Beaufort wind scale was ≥3 (wind 7-10 knots, scattered whitecaps) or if glare from the sun prevented observation. The sampling order was as close to the random selection order as possible, given logistical constraints. Surveys of PSUs were each completed within one day and distributed between 15 May and 31 July.

PSUs were sampled using line transects in which all murrelets observed on the water or flying were recorded along with the perpendicular distance of each bird from the transect line. The size of the vessels were variable and the speed between 8 and 15 knots. Two observers scanned continuously in a 90° arc from bow to beam of the vessel, completing a scan in 4 to 8 seconds. Greatest effort was placed observing directly ahead of the boat near the transect line and in a 45° arc towards the beam of the vessel. Care was taken to detect birds flushing well ahead of the boat. Binoculars were used to aid in species identification. Data was recorded into tape recorders or communicated via headset to someone entering it into a computer. In Washington, data was collected using a software program (DLOG2, developed by R.G. Ford, Inc., Portland, OR.) which interfaced with GPS, GIS maps with bathymetry and a thermosalinograph. Additional data collected included bird behavior, group size, plumage class, weather, sea conditions and water depth.

The distance of each murrelet observation was used, in the program DISTANCE, to select a mathematical function to describe the effect of distance on numbers of groups of birds detected. Assumptions of this method include 1) that all birds near the transect line are observed, 2) that detection is not effected by the response of murrelets to the boat, and 3) distance estimations are accurate. Observer accuracy was maintained through two to four weeks of training prior to the season, surveys completed with an experienced trainer, and tests throughout the season during which distance estimates were required to be within 15% of the actual distance.

Canada

Data are available from six transect routes, which were repeatedly sampled (but not in every year) within the period 1979 to 2006, and two routes sampled in 1996–2000. Most of the data cover the years 1995–2006. Seven of the transects were off southwest Vancouver Island (Clayoquot Sound, Barkley Sound, and the West Coast Trail). Methods varied somewhat among the studies but generally murrelets were counted on both sides of a small vessel running at constant speed along a fixed route and densities were estimated either using an unlimited distance transect (giving densities as birds per kilometer) or within 300 meter-wide strip transects (giving densities as birds per square kilometer). The eight studies reviewed here were all established before provincial standards were in place for sampling Marbled Murrelets at sea. Nevertheless, all conform to these standards with minor deviations. Within each data set there were some inconsistencies in boat type, observer skills, sea and weather conditions, and other variables which confound boat surveys for seabirds, but we found no evidence that these variations were systematic and might have caused the trends which emerge from the data. We used data representative of the breeding season and all surveys fell within the period April 24–July 16, which covers the period that numbers of murrelets were highest and most consistent off Vancouver Island (Burger, 2000, 2001) and Haida Gwaii (Queen Charlotte Islands) (Harfenist and Cober, 2006). We examined each data set carefully to ensure that there was no bias caused by including or excluding data at either extreme in this seasonal range.

APPENDIX B

Surveys of Trevor Channel

Carter Survey Methods

In 1980, Carter (1984) repeatedly surveyed lower Trevor Channel in Barkley Sound, an area with high densities of Marbled Murrelets. The survey was completed 37 times between 16 June and 6 July 1980 and was conducted within a 23.7 km^2 grid (see Carter and Sealy 1990, Figure 1). There were 96 quadrats within the grid, each 0.25 km^2 (500m x 500m), forming 9 rows and 16 columns. Partial quadrats, those intersecting land, were combined in order to maintain a consistent size and shape in all quadrats. Quadrats adjacent to coastline were positioned with 500m between the center of the quadrat and the shore. Quadrats were grouped into 12 regions based upon homogeneity of habitat and proximity (contiguous and condensed rather than in a straight line)

All quadrats within the grid were surveyed during each census and the boundaries of the each quadrat were determined using topography and a compass. A survey was completed between one and four times a day beginning at 05:00, 10:00, 15:00, or 20:00, and required between 2 and 2.5 hours to complete. There were no surveys on eight days of the 21-day nestling period. The skiff with outboard motor, traveled down the center of each quadrat and the observer surveyed 250m on either side and forward to the end of the quadrat. All birds on the water and flying birds were recorded. Birds that landed on or flew up from the water were considered on the water. Fish holding behavior and the age of birds (HY, AHY) were noted. The tide and current at the census midpoint, as well as visibility, precipitation, sea state, and wind speed and direction were recorded. For this analysis, Carter (1984) provided the raw data for each survey, which were not available in his thesis. To accommodate the change in method, we analysed total counts of birds (in and out of transect strips) made in each survey and hence report numbers of murrelets seen on the water within the entire grid area.

Burger and Stewart Survey Methods

Alan E. Burger and E. Anne Stewart censused murrelets in the same area of Trevor Channel surveyed by Carter (1984) between 1992 and 2000. Initially, they used the same

grid pattern as Carter (1984; see above) but in July 1994 switched to a looping 43-km long strip-transect route covering the same area in order to facilitate habitat analyses and hydroacoustic sampling of prey (see Carter and Sealy 1990, fig 1 for the grid map; see Burger, 2000 for the overlapping transect route; see Burger, 2000 and Burger et al., 2004 for methods). The transect was split into 43 1-km sections. Surveys were completed between 5 and 23 times annually, spread over 3 to 11 months of the year.

Between 1994 and 2000, the Trevor Channel transects were completed from small vessels, 4 to 6 m long (viewing height 1.5 to 2.5 m), at a speed of 15 to 20 km/hr (8 to 11 knots/hour) but the boat was slowed in order to count large groups of birds. Each transect began in the morning when murrelet counts were least variable (Carter, 1984). Transects were discontinued if the Beaufort sea state was greater than 3 or rain was heavy. One or two observers surveyed 150 on either side and one minute of travel ahead (250m at 8 knots) of the vessel. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Binoculars were used to confirm species identification. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of Broken Group Islands Inner and Outer

Burger Survey Methods

These data sets come from two non-overlapping routes within Barkley Sound (see Bellefleur et al., 2005, for maps), which were sampled from 1995 to 2006 by trained Parks Canada staff, under the supervision of Bob Hansen, using the Resource Inventory Committee (1997, 2001) protocol. Broken Group Islands (BGI) Inner (9.2 km) ran through the center of the BGI and BGI Outer (14.6 km) ran from the mouth of Ucluelet Harbour across Loudon Channel to end at Turtle Island in the Broken Group. Both routes were sampled using a 300 m wide strip transect, 150 m on either side and one minute of travel ahead (250m at 8 knots) of the vessel. Murrelets outside the transect were also

recorded. Early transects completed by Parks Canada staff may have used a 200m wide strip. Where the strip width was unknown, only linear densities were calculated (A. Burger, oral commun.) We used birds on the water within the transect and report densities as birds per square kilometer.

Each year, the transects were surveyed about twice a month between May and September, with a total of 5 to 10 surveys (Bellefleur, 2005). The BGI Inner and Outer transects were split into six and five legs of variable length, respectively. The entire transect was not completed in every survey. Transects began in the morning when murrelet counts were least variable (Carter, 1984). Sampling was discontinued if the Beaufort sea state was greater than 3 or if rain was heavy. Geographical landmarks, and more recently, Global Positioning System (GPS) were used to navigate during surveys. One or two observers used 4.5 m long inflatable boats with a viewing height of 1.5 m. Boats traveled at 8 to 12 knots but were occasionally slowed or stopped to count or identify birds. Observers used binoculars to aid in species identification and classify plumage. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of West Coast Trail

Burger Survey Methods

This transect ran parallel to the coastline for 64.6 km (vessel approximately 200 m offshore) between Seabird Rocks and Owen Point (map in Burger, 2000), covering the nearshore area with the highest known density of Marbled Murrelets in British Columbia (Burger 1995, 2002). Surveys were initially completed by Alan E. Burger working with Parks Canada staff (1994–96) and subsequently (1997-2006) by the park staff. Birds were counted in a 300m wide strip (150 m on either side of the vessel and one minute of travel ahead, 250m at 8 knots, of the vessel) and we report densities as birds per square

kilometer. Early transects completed by Parks Canada staff may have used a 200m wide strip. Where the strip width was unknown, only linear densities were calculated (A. Burger, oral commun.)

Each year, the transect was surveyed about twice a month between May and September, with a total of 5 to 10 surveys (Bellefleur, 2005). The West Coast Trail (WCT) transect was split into 24 legs of variable length. Each transect began in the morning when murrelet counts were least variable (Carter, 1984). Transects were discontinued if the Beaufort sea state was greater than 3 or if rain was heavy. The entire transect was not completed in each survey. Geographical landmarks, and more recently, Global Positioning System (GPS) were used to navigate during surveys. Two observers used 4.5 m or 8-12m long inflatable boats with a viewing height of 1.5 m or 2.0-3.5m. Boats traveled at 8 to 12 knots but were slowed or stopped occasionally to count or identify birds. Observers used binoculars to aid in species identification and classify plumage. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of Tofino and Flores

Mason Survey Methods

We re-analyzed the data from these two transect routes in Clayoquot Sound recorded in 1996–2000 and previously published by Mason et al. (2002; see this reference for maps and details). Both transects covered large areas of exposed inshore waters and sheltered channel waters in areas of high murrelet densities previously identified from grid surveys (Sealy and Carter, 1984; Kelson et al., 1995). The Tofino transect (49.8 km), sampled annually in 1996–2000, covered exposed waters off the Tofino peninsula and both exposed and sheltered waters around Vargas Island. The Flores transect (82.1 km), sampled annually in 1997–2000, covered exposed and sheltered waters around Flores

Island and off the Catface Peninsula. The Tofino transect was divided into 7 legs in 1996, and in beginning in 1997, the transect was lengthened from 49.75 to 52.7 km and two of the legs were further divided creating a total of 10 legs. (See Manson et al. 2002, table 2-1, Figure 2-1). The Flores transect route was slightly altered, lengthened, and subdivided from 82.1km and 17 legs in 1997 to 95.3 km and 19 legs in 1998-2000.

Transects began in the morning unless delayed by weather. Surveys were occasionally terminated if weather conditions prevented observations, and were not begun if wind was greater than 15 knots and/or sea swell greater than 1m. Geographical landmarks and Global Positioning System (GPS) were used to navigate. 4.5 m inflatable boats were used to survey transects except in 1998, when a 5.5 m fiberglass boat was used in the Flores transect. Observer eye height was 1.5m. Survey speed was 8 to 12 knots but boats were slowed or stopped occasionally to count or identify birds. Observers counted all birds flying and on the water within 150m of either side and one minute of travel ahead (250m at 8 knots) of the vessel, forming a 300m strip. Birds outside of the strip were noted. The age class (HY, AHY) and behavior (flying, on water) of murrelets was recorded as was sea state and wind during the survey. Data was initially collected using a tape recorder and later transcribed.

Resources Inventory Committee 2001 methods

In 2001, a standardized protocol for British Columbia at-sea surveys of Marbled Murrelets was prepared for the Terrestrial Ecosystems Task Force Resources Inventory Committee. This protocol, still in use, requires line transects, replacing the strip transect method of the prior version of this protocol (RIC 1997). To retain comparability with data from previous strip transects, it is suggested that project designers consider combining the techniques of line and strip transects. Thus, the survey could include a strip transect, in which all birds flying or on the water within 50m on either side of the vessel are recorded. (See RIC,1997 for details.) In addition, data would be recorded using line transect methods (see below).

The length and location of the survey depends upon the use of the data. To find the interannual variation of murrelets, select a location with high numbers of murrelets and an area large enough to encompass the majority of local movement among foraging areas (e.g. >30 km). Divide the area of the coast to be surveyed into equal-sized segments bound by geographical landmarks. Transects, roughly parallel to the coast within 1 km of shore at 200m and 600m, are recommended. If there is no baseline data for the area, then a preliminary study would determine the Marbled Murrelet distribution in relation to the distance from shore making it possible to select the optimum distance of the transect from the coastline. Route nearshore transects 150 to 200 m from the surf and parallel to the coast for a minimum of 5 or 10 km. Offshore transects should be a series of straight lines between geographical landmarks, 500 and 600 m from the shoreline. Add additional transects further from shore if murrelets utilize the area. A nearshore transect may be sufficient in locations where murrelets do not use deeper water (e.g. narrow channels, around islands). To determine murrelet habitat preference and local movements, divide transects into small segments (e.g. 500 to 1000m). To monitor population trends or relative abundance, complete a power analysis from a preliminary study to determine the required effort (See Bekker et al. 1997). A minimum of four or five replicate samples during the breeding season is required to resolve murrelet distribution or habitat use. GPS permits accurate replication of surveys. Report the marine ecosection and ecounit (www.luco.gov.bc.ca), biogeoclimatic zones and subzones, ecoregion, ecosection, and broad ecosystem units for the area.

Surveys should be completed between one hour after sunrise and three hours before sunset. Because of weather conditions, early morning is generally a good time to survey but the optimum time could be established through a local preliminary study. Beaufort sea state should be between 0 and 2, when possible. Boat speed should be 8-12 knots but can be slowed or stopped for observers to identify birds or classify plumage. Report boat length and eye height above sea level.

The surveys require two observers and one boat driver but if necessary, one observer can drive while the other records data. Observers scan ahead of the boat to 90° abeam of the

vessel. Observers should focus most on the area ahead of and close to boat. The line transect method assumes that all birds on the transect line are seen and that those closer to the line are more likely to be detected. It may not be necessary to record every bird, particularly those further from the transect line. Record all murrelets on the water. If the murrelet is originally seen on the water, but subsequently flies, the bird is considered on the water. "Flying birds are recorded only when they cross the beam of the boat. The distance is measured at that point. If birds fly in and land, the location where they land is recorded if it is within the 90 degree scanning area" (RIC 2001). For each murrelet observation, record the time, group size, plumage class, distance from boat (direct distance form bird to observer). Calculate the angle from the transect line to the location where the bird was first observed to the nearest 5 degrees using an angle board or digital compass. Note any fish holding and interspecific interactions. Because recording other birds can detract from murrelet observations, it is suggested that the study use a strip transect (50m on either side of the boat) when including other bird species in the survey. Use binoculars to classify plumage. Data collected at the beginning of the survey and then as conditions change include time at the beginning and end of the transect, cloud cover, cloud type, precipitation, wind direction, sea state, wavelet height, and level of glare. Preferably, measure sea surface temperature, tide, salinity, and depth and prey density using an echosounder. Be sure to mark the beginning and end of each segment as well as the location of murrelets on the echosounder paper chart. Record data into a tape recorder and then transcribe to a datasheet and computer database. Distance estimates should be calibrated, using a rangefinders or towing a buoy on 50m or 100m of line, prior to and periodically throughout the survey.

Other Protocols

Gould and Forsell Survey Methods

In 1989, Gould and Forsell developed a protocol using a strip transect method for the U.S. Fish and Wildlife Service in Alaska for at-sea surveys of marine birds and mammals. They referred to three types of pelagic surveys 1) in which there was a preset number of short transects per observation (three 10-min transects per hour, 2) longer transects while the vessel was traveling between points or surveying radials through a study area, and 3) sets of transects selected by habitat. In this last survey type, the number of replications required for a density index was a particularly important consideration. Surveys in bays should have had a carefully selected route, which ideally should sample habitat types in proportion to their availability, and timing of the survey.

The methods described were flexible to encompass surveys under a wide variety of conditions. The basic requirements were a vessel traveling at a constant, known speed, and one observer surveying, for a particular length of time, forward to the end of the transect and in a 90° arc to a specified distance from one side of the vessel forming a strip. The optimum vessel speed was 10 knots but could range from 6 to 15 knots. The preferred strip width was 300m but if the vessel was small and observer height above water low, the strip could be reduced to as little as 200m. Data was collected continuously during transects with a suggested length of 10 minutes. Binoculars were frequently used in order to spot birds. All birds sitting on the water and all birds foraging in flight were recorded if within the strip. Traveling birds, those flying quickly in a straight line, were counted (and flight direction noted) only during 'instantaneous' counts that covered the entire transect area once. Thus, during a 10-min transect at a speed of 10 knots, there were three instantaneous counts extending 1,000m ahead of the ship and 300m to one side, one at the start of the transect, one after 200 seconds, and one after 400s. The instantaneous count area may have been smaller and more frequent.

Effort was made to avoid counting a bird twice. Foraging birds first seen flying outside of the strip and then seen moving into the strip were not counted. Care was taken to include

birds in the strip ahead of the vessel. All sightings of mammals and birds in groups of more than 1000 were counted. The position at the beginning and end of the transect and the speed made good was primarily taken from nautical charts to avoid error in ship navigation systems. Time at the start of the transect, length of the survey in minutes, height of the observers eyes over the water, and the length of the survey was recorded. All birds and mammals were identified to the lowest taxonomic level possible. Observers recorded the age, sex, color phase or plumage, group size, number of birds, flight direction, and behavior. Environmental data, collected when possible, included water depth, water temperature, salinity, coverage and pattern of ice, barometric pressure, weather, wind speed, sea state, swell height, and tide. To calibrate distance estimations 1) practice distances in a harbor using mapped objects, 2) use a rangefinder such as described in Heinemann (1981), or 3) tow a buoy on 300m of line.

Supplementary survey techniques included 1) surveys completed from skiffs in which the strip width was 50-75m to each side of the boat, or if the observer was standing, 75-100m to each side, 2) coastline counts made from a skiff or small ship positioned to maximize the distance from shore, usually 75m, where all birds between the vessel and shore remained visible, 3) one station count from a stationary vessel per survey, usually within a 300-600m radius, with the time that the ship had been stationary prior to the count recorded, and 4) general observations of incidental counts including feeding flocks, large flocks and rare species, as well as unplanned transects.

Ballance Survey Methods

Lisa Ballance (2002) created a seabird survey manual for the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS). Survey routes were planned prior to vessel departure and varied somewhat as mammal observations were investigated. The length of the transect was the time during which all observation conditions were constant. A new transect began when there was a shift in observers (every two hours), a change in the course of the ship >10°, and when there was a change in survey conditions including sea state, side of ship observing from, or observation conditions.

Data was collected by one observer from the flying bridge from just after sunrise to just before sunset, directly into a laptop using the program SeeBird. Seabird surveys were usually discontinued if the Beaufort sea state was above 5 and if rain was more than light. Observers surveyed a 300m strip from one side of the boat with the best viewing conditions, in a 90° arc from bow to beam. The side of the vessel surveyed from was changed as needed. Care was taken to detect all birds within the strip. Data was collected only when the ship was on the transect path. Flocks of birds associated with marine mammals were not counted following the investigation of a mammal sighting. Bird observation data included species, number, distance from the ship at first sighting (includes within 300m on the other side of the ship), association with other individuals, behavior (sitting, following the ship, feeding, piracy, other, unknown, directional flight, non-directional flight), age, sex, time, position, and comments. Flight direction relative to the ship heading was recorded using an angle board for birds in directional flight only. The behavior of each individual in a group of birds was recorded. Birds following the ship were counted once and care was taken to exclude those flushed into the strip by the presence of the ship. Effort data included vessel and cruise, date, latitude and longitude (from ships GPS), sea state, ship's course made good, subjective observation conditions, begin/end transect, time and position (automatically updated every 10 minutes), observation side, and observer. Based upon observer conditions, the strip width was adjusted differently for different sized taxa. Small birds like storm-petrels and phalaropes may have been surveyed for in a 100m, 200m, or 300m strip width, while larger taxa were observed in either a 200m, or 300m strip. Range finders described by Heinemann (1981) were used. To ensure accuracy in distance assessment, estimates were practiced at the beginning of the cruise and periodically throughout. 'Off-effort' data collected included birds, flocks, mammals, fish, turtles, and flotsam but only rare bird (not yet recorded that day), pinniped, turtle, or other unusual animal data were required. Data collected outside of the strip but on transect were not considered 'off-effort'.

A separate survey of flocks was conducted using a strip transect and high powered mounted binoculars. The marine mammal observers present on the flying bridge were required to search for flocks, 5 or more feeding birds, within a strip width of 1 reticle

from the ship. The seabird observer determined the flock size, species composition, behavior of individuals, angle with relative to the ship heading, reticles, and distance to the flock. All species included in the group were recorded including mammals and fish. If the density of birds prohibited collection of solid data, the occurance of flocks was recorded, but all flock data was recorded for just a sub-sample of the flocks. The entire survey was discontinued as necessary.

APPENDIX C

Marbled Murrelet (*Brachyramphus marmoratus*) Activity Patterns and Health in Port Snettisham, Southeast Alaska, 2005

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EXECUTIVE SUMMARY

- From June-August 2005, Wildlife Trust, in collaboration with the Alaska Department of Fish and Game and Carter Biological Consulting, conducted radio telemetry and health assessment studies to examine the activity patterns, movements, post-breeding dispersal and health of Marbled Murrelets (*Brachyramphus marmoratus*) in Port Snettisham (PS), Alaska.

- We captured and radio-marked 32 murrelets over three nights (28-30 June) within PS and the adjoining waters of Stephen's Passage. We determined their movements and activity patterns over periods ranging from 7 to 59 days ($\bar{x} = 25 \pm 12$ days; SD) using three survey techniques: 1) data logger stations inside and at the mouth of PS; 2) boat surveys inside and at the mouth of PS; and 3) aerial surveys throughout the inner passages of Southeast Alaska from Glacier Bay south to Frederick Sound and Chatham Strait.

- We captured an additional 13 birds over 5 nights between 28-29 June and 11-12 July for banding or blood analyses. Forty-four of the captures were adults (after-hatch year birds) and 1 was a recently fledged juvenile (hatch year bird; captured on the night of 30 June -1 July).

- Of 45 birds captured, 8 were observed holding fish. Four of these fish were recovered at the time of capture. Three of the captured fish were large juvenile or first-year subadult Capelin (*Mallotus villosus*); one was a first-year subadult Pacific Sandlance (*Ammodytes hexapterus*).

- Surveys by aircraft, boat, and data logger were conducted on 15, 27 (35 surveys), and 59 days, respectively, between 29 June and 26 August. Survey and monitoring results indicated that the three tracking methods appeared to be similarly effective at detecting the presence of radio-marked birds, with each technique detecting 83-86% of the murrelets known to be present in PS on a particular day (based on being detected by at least one of the three methods).

- The data logger systems provided continuous monitoring over the entire study period, but a restricted reception range (2-3 km) limited their utility as a monitoring tool in deployed areas. In contrast, boat and aerial surveys offered considerable improvements in detection range, but were limited by temporal and, in the case of aerial surveys, financial constraints.

- Murrelets were captured late in the breeding season to provide information on foraging behavior and dispersal movements, although the general location of one nest in the Speel River valley was identified. The presence of numerous fish-holding murrelets indicated that some murrelets were feeding chicks at the time of our captures, while others had completed nesting, based on the presence of a recently fledged juvenile. Late nesting or renesting was also evident at the Speel River nest and by an adult that laid an egg after capture.

- Daily movements and activity patterns were difficult to interpret without definitive evidence of murrelet breeding status, but data logger monitoring supported by opportunistic boat surveys strongly suggested that most radio-marked murrelets departed Port Snettisham in the evening, presumably to feed chicks in nearby nesting areas (some likely outside of the Port Snettisham watershed), then usually returned in the early to mid-morning hours (00:00-06:00).

- We noted some variability in the number of radio-marked murrelets detected in Port Snettisham from day to day, as 22 murrelets left for periods of at least 1 day and up to 9 days before returning to the inlet, although some murrelets may have been present but not detected by any of the methods used on a particular day. During absences from the inlet, most radio-marked murrelets were located within a 50 km radius, especially in the nearby Endicott Arm-Holkham Bay area.

- The number of murrelets attending Port Snettisham declined steadily through the season, as half of the radio-marked birds ceased returning to the inlet by 15 July, and all but 2 had departed by 31 July. One radio-marked murrelet was still present when the data loggers were removed on 26 August.

- Radio-marked murrelets from Port Snettisham were found throughout the inner passages of Southeast Alaska during the post-breeding dispersal period; over 200 km (over water distance) into the middle section of Glacier Bay to the north and 160 km in the direction of Chatham Strait to the south.

INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small diving seabird (Family Alcidae) that breeds in coastal older-aged forests from central Alaska to central California, but also nests on the ground in parts of Alaska and British Columbia (Nelson 1997, Bradley and Cooke 2001). This species generally occurs near shore and is the most common alcid in the sheltered waters of its range. *Brachyramphus* murrelets (i.e., Marbled, Kittlitz's *B. brevirostris*, and Long-billed *B. perdix*) are unique among alcids in flying long distances inland to their solitary nests (generally within 40 km; Day et al. 1983, Nelson and Hamer 1995, Piatt et al. 1999). Because breeding Marbled Murrelets are cryptic, secretive, and primarily crepuscular in their flights and at nest sites, relatively little is known about their activity patterns and few active nests have been found, particularly in Alaska (DeGange 1996). Marbled Murrelets are currently listed as threatened in California, Oregon, Washington, and British Columbia, and are thought to be declining over much of their range because of breeding habitat loss and effects from oil spills, gill-net fishing, and possibly climate change (USFWS 1992, 1997; Burger 2002, McShane et al. 2004).

Southeast Alaska is generally considered the center of abundance for Marbled Murrelets (henceforth murrelets) in North America (Piatt and Naslund 1995). Surveys at inland sites in this area have provided some information on murrelet activity patterns in the forest (e.g., Brown et al. 1999). In addition, observations made during boat-based surveys in Southeast Alaska have indicated that local murrelet numbers fluctuated seasonally (Agler et al. 1998, Speckman et al. 2000), and suggested that murrelets can fly long distances between nesting and foraging areas during the breeding season (DeGange 1996; G. van Vliet, M. McAllister, unpubl. data). With the advancement of small alcid capture and radio-marking techniques in the late 1990s (Whitworth et al. 1997, Newman et al. 1999a, b), long distance at-sea movements by murrelets were verified in Southeast Alaska (Whitworth et al. 2000). Murrelets were also successfully tracked to nest sites in many areas of their range providing detailed information on inland activity patterns and nesting habitat selection in Southcentral Alaska (Kuletz et al. 1995), central California (Burkett et al. 1999, Peery et al. 2003), and British Columbia (Lougheed 2000, Hull et al. 2001, Bradley 2002). While these data have provided us with a more complete picture of murrelet ecology in other areas, we still know very little about murrelet activity patterns and habitat use in Southeast Alaska. Determining specific flight patterns, habitat preferences, and murrelet ecology in the core of the species range will be critical for effective management actions and conservation efforts in their nesting habitats and at-sea foraging areas.

Concurrent with murrelet telemetry studies in central California (Burkett et al. 1999), blood samples were collected to evaluate the health and physiological condition of breeding individuals. Baseline health indices were established for murrelets inhabiting central California, resulting in a better understanding of murrelet hematologic parameters, immune function, liver enzymes, kidney function, and electrolyte balance (Newman and Zinkl 1998, Newman 2000). Establishing baseline health indices for murrelets in Southeast Alaska will enable future comparisons to other parts of their range to better understand the effects of extreme environmental conditions (e.g., El Niño, La Niña, algal blooms, disease) and anthropogenic problems (e.g., oil spills, pollutants, disease). Furthermore, baseline health indices also play a vital role in helping veterinarians assess the health and releasability of oil injured or diseased murrelets receiving care. To date, only one blood-based health assessment has been conducted

on murrelets from Alaska from the Shumagin Islands (Newman et al. 1997). It is unknown if murrelets from Southeast Alaska are physiologically healthy or have conditions that would place them at a survival disadvantage.

In 2005, Wildlife Trust and collaborators began a multi-year project to study the health, activity patterns, foraging ranges and habitat use of murrelets in the Port Snettisham area of Southeast Alaska. This project builds upon work begun by the Alaska Department of Fish and Game (ADFG) on murrelet activity patterns at Port Snettisham in 2004 (M. Kirchhoff, unpubl. data). This report summarizes data during the late breeding and post-breeding periods in 2005. A separate report will be provided on baseline health parameters.

STUDY AREA

We captured murrelets in or at the mouth of Port Snettisham (PS; 57°58′N 133°53′W), a relatively large, T-shaped, deepwater inlet east of Stephen's Passage, approximately 40 km south of Juneau in Southeast Alaska (Fig. 1). PS is located 150 km from the open ocean and protected from oceanic circulation patterns by Admiralty and Chichagof islands. Strong tidal action mixes saltwater with freshwater originating from the Speel and Whiting rivers, and Gilbert and Sweetheart creeks. PS is relatively undeveloped except for a fish hatchery and airstrip in the northeastern end of the inlet in the Speel River arm. Our research was focused in PS, but aerial surveys for radio-marked birds were conducted throughout the interior waterways of Southeast Alaska from as far north as Glacier Bay and Lynn Canal, and as far south as Baranof, Zarembo and Wrangell islands.

METHODS

Capture and Handling

Murrelets were captured at night using an established spotlight and dip-netting technique (Whitworth et al. 1997, 2000) over five nights between 28-29 June and 11-12 July, 2005 (Table 1). Three-person capture crews (consisting of a boat driver, spotlight operator, and dip-net handler) searched for murrelets in an inflatable Zodiac craft using high-intensity spotlights. After locating a single murrelet or group of murrelets, we kept the spotlight beam focused on one bird and approached at moderate speed. We attempted to net murrelets as they remained on the water surface, but most birds were captured following short escape dives after they resurfaced beside the Zodiac in an area illuminated by the spotlight. Capture times and locations for all murrelets were recorded with a hand-held GPS. Once captured, individual birds were placed in cardboard pet carriers and transported by a second support boat (5 m Alumaweld skiff) to the larger chartered research vessel (15 m *M/V Heron*) or our beach base camp (4-5 July only) for processing. To test our capture techniques, we also captured a few birds on the night of 27-28 June but released birds immediately after capture.

Handling procedures included a physical examination, morphological measurements (culmen/tarsus/wing chord/weight), brood patch evaluation (Sealy 1974), a photograph, banding

with a U.S. Geological Survey stainless steel band, radio-marking (*see below*), and blood sampling (*see below*). Most murrelets were subjected to all the above procedures, with these exceptions: 1) no birds were radio-marked after the last transmitter was attached at 00:54 h (all times Alaska Daylight Time) on 1 July; 2) morphological measurements (other than weight) were not taken on 4-5 July; 3) a fledged juvenile murrelet captured on 30 June -1 July was not banded or radio-marked; and 4) the single murrelet captured on 11-12 July was banded, checked for a brood patch and immediately released from the Zodiac. After processing, birds were returned to the Zodiac (via the support boat) and released in Stephen's Passage near the capture location.

Radio Marking

We attached radio transmitters using the subcutaneous anchor method (Newman et al. 1999a, b), but were not able to use the Isoflurane inhalant sedative due to equipment malfunction. VHF radio transmitters (Model A1555 ATS, Isanti, MN) weighed approximately 2.5 g (~1% of murrelet body weight) and were equipped with a 15-cm external whip antenna, subcutaneous anchor, and rear suture port. Murrelets were positioned with the back arched slightly and wings slightly extended, then the feathers covering a small area on the back of the bird were wetted with alcohol and parted to expose the skin where the anchor was to be inserted. The anchor was placed subcutaneously and tissue glue applied to the bottom of the radio, which was attached to feathers beneath the base of the radio. Finally, a subcutaneous suture was placed at the level of the suture port at the caudal end of the radio. Following the procedure, birds were inspected to make sure the anchor was in place, the radio was securely attached, and wings had full range of motion.

Radio Telemetry Tracking

Aerial Surveys – Aerial telemetry surveys were conducted throughout Southeast Alaska from 3 July to 9 August (Table 2). All aerial surveys were conducted during daylight hours (07:45-20:30 h) in single engine amphibious Cessna 206 aircraft operated by Air Excursions (Juneau, AK) and Tal Air (Juneau, AK). Early surveys focused on areas near PS and Stephen's Passage from Frederick Sound north to Taku Inlet (Fig. 1), including the Whiting and Speel River basins, Endicott Arm-Holkham Bay area, and Seymour Canal. After most birds had dispersed out of PS, we expanded surveys to cover most of Southeast Alaska from Inian Island at the west end of Icy Strait to Drake Island in Glacier Bay and Lincoln Island in Lynn Canal in the north, south to Zarembo Island and Wrangell in Sumner Strait, Cape Decision on Kuiu Island, and the southeast tip of Baranof Island in Chatham Strait.

Aircraft were equipped with a R2100 receiver, 2 x 4-element Yagi directional antennas mounted on wing struts, a left-right antenna switchbox, and headphones. We recorded the time and latitude-longitude coordinates for most radio-marked murrelet locations on a handheld GPS receiver, although to conserve flying time, only a general location (i.e., Speel River, Whiting River, PS mouth or inlet) was recorded for some murrelets detected within PS. We determined the locations (within approximately 1 km) of radio-marked murrelets by boxing in transmitter signals, relying on the relative strength of signals received through the antenna switchbox to

direct the pilot to the approximate location and entering GPS coordinates when the signal was strongest.

Data Logger Monitoring – We employed 2 x R4500 receiver/data loggers (ATS, Isanti, MN, USA) to continuously scan transmitter frequencies at 2 prominent locations in the PS area (Fig. 2). Data logger station A was located on the south shore of the inlet mouth near Point Anmer from 29 June to 26 August. Station B was initially placed at the southeastern end of the inlet near Sentinel Point (B1) from 30 June to 6 July, but was relocated to Fannie Island (B2) in the northeast portion of the inlet near the Speel River from 6 July to 26 August. Data loggers were connected to 2 x 4-element Yagi directional antennas mounted on a 3 m mast and were powered by 12-volt marine deep cycle batteries. We set data loggers to switch the target frequency every 2 sec if no signal was detected. Received signals were monitored for 7 sec, recording date, time, frequency, signal strength, number of signal pulses, and pulse rates for each frequency detected. Information from data loggers was downloaded and batteries were changed every 1 to 2 weeks.

Boat-based Monitoring –Boat-based telemetry monitoring was conducted in PS from 29 June to 1 August (Table 3). This monitoring was conducted when time and conditions permitted, but we attempted to vary survey times to obtain data on radio-marked murrelet activity patterns throughout the day for comparisons with datalogger data. Most boat monitoring was conducted from the Zodiac, although a few surveys were conducted from the *R/V Heron* or Alumaweld skiff. We established 9 boat-based monitoring stations covering most of the inlet from the mouth of PS at Stephen's Passage (stations 1, 2 and 3), east through the inlet channel (stations 4, 5 and 6) and to the Whiting and Speel River mouths (stations 7, 8 and 9) in the east (Fig. 2). Stations monitored during each survey varied, but overlap among stations later indicated that all of PS (except perhaps some of Speel Arm and Gilbert Bay) could be covered with 2-3 stations. We estimated the approximate coverage area for surveys conducted on 29-30 June and 2 July, prior to establishment of the 9 fixed survey stations.

We scanned for all transmitters at each station using a R2100 receiver (ATS, Isanti, MN) equipped with a handheld "H" antenna and headphones, and recorded relative signal strength (strong, medium, weak) and direction of the strongest signal received for each frequency detected. However, we could not obtain precise location coordinates during boat surveys, therefore, we used station coordinates as the best estimate of bird locations for assessments of radio-marked murrelet activity patterns within PS.

Means are reported $\pm$ SD.

RESULTS

Capture and Banding

We captured a total of 45 murrelets over 5 nights between 28-29 June and 11-12 July (Table 1). Forty-four of the captures were adults (after-hatch year birds) and 1 was a recently fledged juvenile (hatch year bird; captured on the night of 30 June -1 July). We radio-marked 32 of the murrelets over 3 nights between 28-29 June to 30 June -1 July (the juvenile and one adult were

banded only). Another 11 murrelets were captured on 30 June -1 July or 4-5 July to increase samples for blood-based health assessments. Murrelets were captured alone (n = 13), from pairs (n = 22), or from larger groups ranging in size from 3-5 birds (n = 10). However, most birds observed during captures were in singles or pairs.

Eight (18%) adult murrelets (including seven radio-marked birds) were observed holding fish prior to capture (Table 4) and four murrelets (9%) were captured while still holding their prey. Three of the captured prey fish were large juvenile or first-year subadult Capelin (*Mallotus villosus*) with weights ranging from 4.3-5.0 g, while the other was a first-year subadult Pacific Sandlance (*Ammodytes hexapterus*) weighing 10.1 grams.

Mean handling time (which included transportation time from the capture location to the *R/V Heron* or base camp and back) was 70 ± 25 min (n = 44), but ranged from 35 to 123 min. Birds that were radio-marked (including morphological measurements and blood sampling) required considerably more handling time (76 ± 24 min; n = 32) than those not radio-marked (54 ± 19 min; n = 12). We did not note any relationship between total handling time and tracking duration ($r^2 = 0.03$, $p = 0.32$) or attendance period in PS ($r^2 < 0.01$, $p = 0.75$). Small sample sizes and large coefficients of variation precluded determination of effects of handling times on murrelet survival or post-release behavior.

Mean murrelet weight (excluding the single juvenile which weighed 125 g) was 218 ± 19 g (n = 43) and ranged from 188 to 266 g. The heaviest bird in our sample (266 g) had a completely defeathered brood patch (BP score = 3), but passed an egg on the skiff as it was being transported for release. All adult murrelets displayed obvious brood patches; 33 (73%) had BP scores of 3 (completely defeathered), six (13%) had BP scores of 3.5 (starting to refeather), four (9%) had BP scores of 4 (refeathering), and 1 (2%) had a BP score of 4.5 (mostly refeathered). Brood patches in alcids are defeathered during incubation, do not start to refeather until some time after hatching (for single or first nesting attempts), and are not completely refeathered until after fledging. Based on information from brood patches, fish-holding observations, and the one juvenile captured, we considered our marked sample to include mainly chick-rearing birds, with a few late-incubating or completed-breeding (i.e., fledged chicks or nesting failure) birds.

Mean culmen length was 15.6 ± 0.9 mm (range = 13.9 – 17.7 mm; n = 34), mean tarsus length was 21.3 ± 0.8 mm (range = 18.8 – 23.0 mm; n = 34), mean wing length was 132 ± 4 mm (range = 124 – 141 mm; n = 34) and mean bill depth was 6.3 ± 0.4 mm (range = 5.7 – 7.0 mm; n = 34). There were no correlations (all $r^2 \leq 0.10$; all $p > 0.05$) among any morphological characters measured.

Radio Telemetry Tracking

Individual radio-marked murrelets were tracked over periods ranging from 7 to 59 d ($\bar{x}$ = 25 ± 12 d; Table 4).

<u>*Aerial Surveys*</u> - We conducted 15 aerial surveys, although the survey on 13 July was abandoned shortly after take-off due to mechanical problems with the aircraft. A total of 198 locations ($\bar{x}$ = 14 ± 11 murrelets survey^{-1}; excluding 13 July) were recorded during aerial surveys, including

117 locations in PS and 81 outside PS (Table 2). Individual survey totals ranged from 2 to 31 radio-marked murrelets, with significant decreases ($r^2 = 0.84$, $p < 0.0001$) in the number of birds detected over time. Every radio-marked bird was detected at least once during aerial surveys (maximum = 13 surveys), with a mean of 6 ± 3 aerial locations murrelet^{-1} (Table 4). Six radio-marked murrelets were never located within PS and six were never located outside of PS during aerial surveys. One bird (radio frequency #524, hereafter referred to by bird number) was repeatedly detected on land on Admiralty Island soon after marking and was presumed to have been eaten by a Bald Eagle (*Haliaeetus leucocephalus*) which nest in relatively high densities on the island.

<u>*Data Logger Monitoring*</u> - A total of 2732 detections were recorded for 30 of 32 radio-marked murrelets during 59 days of continuous monitoring at data logger stations (Table 5), including 1929 detections ($\bar{x}$ = 33 ± 29 detections day^{-1}) at station B and 803 detections ($\bar{x}$ = 14 ± 30 detections day^{-1}) at station A. Daily detection totals ranged from 0 to 198 detections at station A and 0 to 94 detections at station B. Detections were recorded every day from 29 June to 26 August, except 11 and 23 August.

The mean daily detection total for station A was strongly influenced by high detections on the first 3 nights when several radio-marked murrelets remained in the vicinity for prolonged periods, apparently recuperating from handling (Table 5). Excluding capture days reduced the detection total at station A to 448 and the daily detection mean to 8 ± 11 detections day^{-1}. In contrast, high numbers of detections were not recorded on capture days at station B far from the release area. Regardless, the number of detections was significantly higher (paired $t_{55} = 7.91$, $p < 0.0001$) at station B compared to station A. We noted significant reductions in daily detection totals over time at both stations (A: $r^2 = 0.46$, $p < 0.0001$; B: $r^2 = 0.62$, $p < 0.0001$).

The number of radio-marked murrelets detected ranged widely from 0 to 16 murrelets day^{-1} at both stations, with significantly higher numbers (paired $t_{57} = 4.27$, $p < 0.0001$) inside PS ($\bar{x}$ = 6 ± 5 murrelets day^{-1}) compared to the inlet mouth ($\bar{x}$ = 4 ± 4 murrelets day^{-1}). There were strong correlations ($r^2 = 0.53$, $p < 0.0001$) in the number of birds detected at each station, with significant reductions observed over time at both A ($r^2 = 0.63$, $p < 0.0001$) and B ($r^2 = 0.77$, $p < 0.0001$). Fig. 7 depicts this relationship for all tracking methods.

Data logger monitoring recorded on average 85 ± 99 detections per murrelet, with detection totals for individual birds ranging widely from 0 to 482 detections (Table 4). The total number of days radio-marked murrelets were detected in PS also ranged widely (0-45 d) with a mean value of 13 ± 10 d (Table 4). All but 2 radio-marked birds (#524 and #543) were detected at least once at station A, while 3 birds (#524, #543, and #964) were not detected at station B.

<u>*Boat-based Monitoring*</u> - We conducted 35 boat-based surveys over 27 days at the 9 stations in PS (Table 3). Multiple surveys within a day were conducted on 8 days. The number of individual radio-marked murrelets detected during a survey (i.e., most murrelets were detected at multiple stations during a single survey so we included these birds only once per survey) ranged from 0 to 20 birds, with significant decreases ($r^2 = 0.69$, $p < 0.0001$) over time (Fig. 7). Excluding monitoring conducted prior to the release of the last radio-marked murrelet on 1 July, we detected on average 10 ± 6 murrelets survey^{-1}, with 29 (91%) of 32 birds detected during at

least one survey. Only birds #524, #543 (neither detected by data loggers in PS), and #784 were not detected on any survey.

The mean number of radio-marked murrelets detected at the individual monitoring stations ranged from 3 murrelets survey^{-1} (station 9) to 7 murrelets survey^{-1} (station 5; Table 6). The number of radio-marked murrelets detected at each station was quite variable, with a mean CV for all 9 stations of 0.93 (range = 0.59-1.41). Minimum and maximum survey totals at each station were quite consistent, ranging from 0 to 12-14 murrelets, although station 7 had much higher (20 murrelets) and station 9 much lower (5 murrelets) maximum survey totals.

Comparison of Data Logger and Aerial/Boat Survey Data - Sixty-nine percent of radio-marked birds present in PS on a given day were detected by all tracking methods employed (Table 7), with aerial surveys and data logger monitoring detecting 86% of the murrelets present, while boat surveys detected 83%. Similar proportions (12-17%) of radio-marked birds were also "missed" (not detected) by each method (Table 7). Nineteen percent of radio-marked birds recorded by data loggers in PS on a given day were not detected during boat-based surveys, while 13% were not detected during aerial surveys. Movements out of PS before or after night/early morning data logger detections undoubtedly accounted for some, if not most, of these "missing" birds during aerial and boat surveys in PS (*see Daily Activity Patterns below*).

Direct comparisons of concurrent surveys with boats and data loggers revealed spatial limitations with the data logger system. Boat station 7 and data logger station B were separated by just over 1 km (Fig. 2), but 5 (38%) of 13 murrelet signals detected at station 7 on the evening of 6 July were not detected by the data logger. Similar results were noted on the evenings of 9 and 10 July, when 42% and 55%, respectively, of murrelet signals were not detected by the data logger. No murrelets signals picked up by the data loggers were missed during boat surveys at the same time of day.

Activity Patterns in Port Snettisham

Daily Activity Patterns - Strong temporal differences (χ^2_{11}= 255.22, $p < 0.0001$) occurred in the distribution of detections between data logger stations (Table 8; Fig. 3). Excluding capture days (29 June-1 July), detections at station A were strongly skewed to the late night-early morning (20:00-06:00 h) period, when 77% of all detections were recorded, but relatively few detections (7%) were recorded in mid-day to evening hours (12:00-20:00 h). In contrast, detections at station B were more evenly distributed (and much more numerous) throughout the day, with only slight peaks in activity in the mid-morning period (02:00-06:00 h) and evening to late night (20:00-22:00 h) periods. Inspection of detection patterns for most individual birds (Appendix 1.1-1.32) reinforced temporal differences in spatial distribution described above.

Considerable temporal differences also occurred between survey totals at boat stations deep inside PS (stations 7, 8 and 9), in the channel (stations 4, 5 and 6) and at the mouth (stations 1, 2 and 3) of PS (Fig. 4). Surveys totals at the mouth peaked just after midnight then declined through the morning until few birds were present by midday. Numbers began increasing slowly through the afternoon and into the evening. In contrast, survey totals inside PS peaked in the evening, but declined sharply through the night until midnight when numbers began gradually

increasing through the morning and afternoon. No such obvious trends were noted in the channel, where numbers peaked somewhat in the early morning and mid-evening, but otherwise were relatively constant. Seasonal declines accounted for some low and zero survey totals observed in Figure 4, however many low survey totals were also observed early in the season (Fig. 5).

Strong differences ($\chi^2_{11} = 51.78$, $p < 0.0001$) also occurred in the timing of movements into and out of PS ($n = 82$ inbound and 48 outbound flights) as determined from detections for 23 individual birds passing both data logger stations over relatively short (0-3 h) time periods (Table 9; Fig. 6). Nearly 75% of movements into PS occurred in the early-mid morning hours (00:00-06:00), while 69% of flights out occurred in the evening to early morning (20:00-02:00 h). Little or no movement into (2%) or out (0%) of PS was recorded from 12:00 to 18:00 h.

Inferred movement patterns into and out of PS from data logger detections were supported by results from extended boat surveys conducted on 5 July. Only one radio-marked murrelet was present at 02:45 h when monitoring began at the east end of the PS channel (station 5), but 16 more murrelets were detected moving into the area over the course of the 2-hour survey. Subsequent arrivals occurred as follows: 4 murrelets between 02:45 and 03:00 h; 2 between 03:00 and 03:15 h; 4 between 03:15 and 03:30 h; 3 between 03:30 and 03:45 h; 1 each between 03:45 and 04:00 h and 04:00 and 04:15 h; and 2 between 04:15 and 04:30 h. Signal strength from the directional antenna indicated that all of birds were apparently flying into PS from the west. Seven of the 17 birds remained within detection range for only brief periods (i.e., a few minutes to less than 1 hour), but 10 murrelets were still in the area when the survey ceased at 04:45 h.

Boat surveys also conducted on 5 July indicated that many radio-marked murrelets moved out of PS and into Stephen's Passage and beyond. Twenty murrelets were present in a large feeding flock near Fanny Island in Speel Arm (station 7) at 19:00 h, but numbers steadily declined during subsequent surveys such that only 16 murrelets were present at 21:00 h, 9 at 22:00 h, and 2 each at 23:00 h and 24:00 h. A later survey detected 9 of these murrelets at the mouth of PS (station 2) at 01:00 h the following morning (6 July).

Ten radio-marked murrelets detected outside of PS during aerial surveys (usually in Tracy and Endicott Arms of Holkham Bay) were also detected the same morning or night at PS, before and/or after the daytime locations. The minimum time recorded between detections at the mouth of PS and the Endicott Arm-Holkham Bay area was 102 min for locations separated by 35 km.

Potential Nesting Areas – Only 2 radio-marked murrelets exhibited attendance patterns consistent with incubation (i.e, alternating days of presence and absence) as determined by daytime detections (06:00-20:00 h) in PS. One of these, bird #762, appeared to be incubating at a nest in the Speel River basin about 35 km from the mouth of PS (Fig. 8). Detection patterns (Appendix 1.21) suggested that this nest likely hatched or failed on 12-13 July when detections in PS abruptly ceased until this bird reappeared sporadically between 20 July and 6 August. The other murrelet, bird #503, exhibited sporadic attendance for 12 days after marking (Appendix 1.9), but established strong alternating days of attendance in PS from 11 to 25 July. Afterwards, this bird continued to visit PS on a nearly daily basis and was still attending PS when data

loggers were removed on 26 August. Data for the 30 other radio-marked murrelets, including the 8 fish-holding murrelets, indicated periods of daily attendance in PS or were inconclusive, which precluded incubation (Appendices 1.1-1.32).

Flights suggestive of chick-feeding forays into PS (i.e., brief flights into and out of PS during crepuscular hours) were observed for 9 radio-marked murrelets, including the individual known to be nesting in the Speel River basin (e.g., see Appendix 1.21 on 12 July from 00:00-02:00 h), but data demonstrating such flights was quite infrequent. Limitations of the data logger systems reduced our ability to assess how often such chick-feeding flights occurred. Still, these few instances indicated potential nesting behavior for some birds in the PS watershed.

Seasonal Activity Patterns – Numbers of radio-marked murrelets attending PS declined steadily over time (Fig. 7), both seasonally (last detection in PS; $r^2 = 0.85, p < 0.0001$) and daily (number detected in PS each day: $r^2 = 0.83, p < 0.0001$). Half of the marked birds had definitively left PS by 15 July (about 2 weeks after marking), and all but 2 had dispersed by 31 July (about 1 month after marking).

Numbers of marked birds detected in PS exhibited some day to day variability (Fig. 7), and many murrelets apparently left the area on certain days. Twenty-two radio-marked murrelets were absent from PS for at least 1 day and up to 9 days before returning, although most absences were shorter (Table 10). Fifteen radio-marked murrelets were located outside of PS prior to their last detection in the inlet, but, with only one exception, all locations outside of PS for returning murrelets were within 50 km, in areas such as Endicott Arm-Holkham Bay, Seymour Canal or Stephen's Passage (Fig. 8).

Data logger detections for bird #503 indicated that morning arrival times in PS occurred significantly later ($r^2 = 0.36, p = 0.0005$) as the season progressed (Fig. 9). Samples of morning inbound flights were too small to examine arrival times for 18 other individuals, but considerable variability was observed in arrival times for all birds (Fig. 9).

Post-Breeding Dispersal – Post-breeding dispersal for an individual was considered to have begun after the last detection (using any survey method). We obtained post-breeding dispersal data for 17 (53%) radio-marked murrelets. Marked birds began post-breeding dispersal as early as 30 June, with a mean departure date of 17 July (± 12 d), although one bird (#503) attended PS until at least 26 August (Appendix 1.9). The number of dispersal locations for individual radio-marked murrelets ranged from 1 to 8, over periods ranging from 1 to 30 days after departure from PS.

Of the dispersing radio-marked murrelets found, all were within a 150 km radius of PS during the post-breeding dispersal period, with locations as far north as Glacier Bay and Icy Strait and as far south as Chatham Strait off Kuiu Island (Fig. 10). However, over-water distances from PS to dispersal locations were in most cases considerably longer than radial distances. Over-water travel exceeded 200 km for murrelets located in Glacier Bay, the most distant destination. Aerial locations outside PS were significantly farther ($t = 5.15, p < 0.0001$) from PS for departed murrelets ($\bar{x} = 94 \pm 59$ km; range = 19-203 km) than for compared continuing to attend PS ($\bar{x} = 40 \pm 18$ km; range = 12-103 km).

DISCUSSION

The first year of this project yielded important and unexpected results which will have significant implications for future telemetry and population monitoring studies in PS. We have: 1) identified suitable capture areas and refined capture techniques to ensure sufficient samples for future telemetry studies; 2) evaluated different telemetry tracking techniques for the PS area; 3) determined daily and seasonal activity patterns for murrelets attending the PS area; 4) identified PS as an important regional foraging area; 5) documented long-distance movements from PS for murrelets during the post-breeding dispersal period; 6) established baseline health parameters for the local murrelets population; and 7) identified local prey species used by murrelets during the chick-feeding period.

Daily Movements – Overall flight patterns, especially the timing of inbound and outbound flights, strongly suggested that many marked murrelets left PS in the evening, presumably to feed chicks in unidentified nesting areas (at least some and likely most outside of the PS watershed) or forage in large channels or other inlets. Individuals usually returned after dawn to PS. This pattern was consistent for both boat surveys and data logger monitoring, and corresponded reasonably well with trends from shore-based counts of murrelets flying into and out of PS throughout the day (M. Kirchhoff, unpubl. data). However, these results form a striking contrast with observations in early July 1991 when 1,450 murrelets from streamed out of PS to the south between 04:00 and 05:40 h, with only 1 seen entering the inlet (M. McAllister, unpubl. data).

At Auke Bay, AK (Speckman et al. 2000 and Whitworth et al. 2000) and Clayoquot Sound, BC (Tranquilla et al. 2005), murrelets also moved out of inlets at night and returned in the early morning hours mimicking our data from PS. In Barkley Sound, BC, large numbers of murrelets moved out of Trevor Channel in the afternoon and evening, and returned at dawn, but some remained in the channel at night (Carter and Sealy 1984, 1990). This is in contrast to Desolation Sound, BC, where murrelets were present in the inlet throughout the day and night during the breeding season (Tranquilla et al. 2005). In central and northern California, breeding murrelets foraged widely during the day but returned to congregate off the mouths of rivers at night before flying inland at dawn (Burkett et al., unpubl. data).

Numerous individual exceptions were noted to the overall movement patterns observed in 2005 (i.e., into PS in the morning, out of PS in the evening and night). Ten radio-marked murrelets were detected on at least one occasion leaving PS in the morning and/or returning at night on the same day that they also were detected during midday outside of PS. Similarly, bird #762 (known to be nesting along the Speel River), was captured and detected several times at the inlet mouth, suggesting movements out of PS for foraging, although this bird was never located outside PS during aerial surveys and observed movements were limited to within 25 km of nest site. Hull et al. (2001) found murrelets on the water at distances averaging 39.2 $\pm$ 23.3 km (range 12-102 km) from nest sites, and these birds spent 0.3-3.5 hours per day commuting to and from nests. Whitworth et al. (2000) found potentially nesting murrelets ranging up to 124 km ($\bar{x}$ = 78 + 27 km) from inland sites.

Variation in activity patterns and movements among individuals is expected, and it is not unusual for a portion of birds in a population to follow a different pattern than the average. However, we remain uncertain about differing benefits for birds that foraged in PS during the daytime but left at night, compared to those that left PS during the daytime and returned at night. Possible explanations are: (1) some marked murrelets nested in the PS watershed, while others nested elsewhere; and (2) incubating, chick-feeding, and completed-breeding birds have different foraging requirements. Incubating birds must find sufficient resources for themselves to survive 24 h on the nest without food; chick-feeding adults must find relatively large prey to take to the nest each visit; and post-breeding adults may or may not continue to attend nests for a period of time after breeding (Carter 1984, Carter and Sealy 1987, 1990; Hebert et al. 2003, unpubl. data). Proportions of birds feeding in PS during the day and night in July may vary between years related to spatial and temporal availability of appropriately-sized chick prey and timing of murrelets breeding. More definitive statements about the activity patterns of murrelet nesting in PS should await further studies.

Interpreting the daily movements and activity patterns of individual radio-marked murrelets without definitive data concerning their breeding status or general nesting areas was more challenging. Even the movements of bird #762, whose breeding status and nesting area were identified, appeared inconsistent and difficult to characterize (Appendix 1.21). Qualitative assessments of attendance patterns indicated that 13 radio-marked murrelets attended PS on a nearly daily basis, but 9 birds exhibited much more sporadic attendance in PS interspersed with forays outside the inlet during the daytime, and another 9 murrelets departed PS soon after radio-marking. The lack of consistent patterns for some marked murrelets was at least partly the result of our inability to reliably detect birds as they passed data logger stations, particularly at the mouth of PS. A single missed detection at the mouth of PS during an inbound or outbound flight would radically alter our interpretation of individual movements on a given day.

Locating Potential Nesting Areas – In 2005, we radio-marked murrelets in late June/early July to determine activity patterns during the chick-rearing period and post-breeding dispersal movements for birds using the PS area. Our efforts were too late in the breeding season to determine nesting areas for the all but 1 radio-marked bird. Finding nests during brief chick-feeding visits to nest sites would be extremely difficult with tracking methods employed. However, the potential to find nests via aerial telemetry was demonstrated by locating a presumed incubating bird (#762) during aerial surveys at an inland site along the upper Speel River (see Fig. 8). Radio-marking earlier in the breeding season in subsequent years should result in a greater number of nest locations.

Based on characteristic on/off detection patterns (i.e., on the nest one day and on the water the next day; Bradley 2002), bird #762 appeared to be incubating at a nest for 13 to 14 days after capture, but abrupt changes in attendance in PS after that point indicated that the nest likely failed. Given that incubation continued after handling, immediate effects from marking and handling did not occur, but later radio effects may have contributed to nest failure (Ackerman et al. 2004). Bird #503 exhibited sporadic attendance in PS for 12 days after marking and then established strong alternating days of attendance (on/off pattern) in PS, remaining in the inlet until after the data loggers were removed. Sporadic attendance after marking may have indicated

effects of marking and handling. Late egg laying in mid-July (about two weeks after marking) are consistent with a replacement egg (Hebert et al. 2003, Tranquilla et al. 2003).

Seasonal Attendance Patterns – We radio-marked seven fish-holding adults that were feeding chicks at the time of marking. Some may have been near the end of the chick period, given the presence of at least one recently-fledged murrelet on 30 June. This juvenile indicated that some murrelets had started nesting by 30 April, assuming incubation and chick rearing periods of 30 days each. Some egg laying could certainly have occurred before 30 April, as noted in BC (Carter 1984, Carter and Stein 1995). Bird #762 demonstrated attendance patterns on and off a nest site until 12 July, indicating egg laying on or near 12 June. Bird #503 appeared to lay an egg on about 11 July; this could have been a replacement egg and may not be representative of most of the population. Based on attendance and movement patterns of radio-marked murrelets, most birds apparently had completed chick rearing by mid- to late-July when >50% of radio-marked birds left PS. By 25 July, over two-thirds of radio-marked birds had left PS and by 31 July only 2 marked birds remained in the inlet.

Consistent seasonal declines in numbers of radio-marked murrelets attending PS waters were expected as murrelets dispersed post-breeding. However, ADFG shore-based counts found peak numbers of murrelets flying into and out of PS around 15 July (M. Kirhhoff, unpubl. data) about the same time as half of the radio-marked sample had already departed PS. Peak fish-holding behavior based on ADFG ground and boat-based observations also occurred between 23 July and 3 August (C. Millow, unpubl. data), when all but 2 radio-marked birds had left PS. Because chick rearing usually extends to early or late August in AK and BC (Carter and Stein 1995, Hamer and Nelson 1995, DeGange 1996), we suspect that our radio-marked sample bred earlier than many other birds in the population. Captures may have inadvertently targeted earlier breeders, possibly because they were more prevalent in PS at night at the end of June. However, if PS served as an important regional foraging area as our data suggest, peak shore-based counts in mid-July could have reflected either the period when most pairs were actively feeding chicks, or an influx of birds from outside PS that had finished chick rearing. Assuming post-breeding dispersal occurred soon after cessation of active breeding activities (i.e., chick fledged or nest failed), relatively early dispersal from PS by radio-marked murrelets also may have indicated failed nesting or mortality by some radio-marked birds, reflecting potential marking, handling or radio effects. Earlier capture and radio-marking efforts in 2006 will provide comparative data for better evaluation of potential explanations.

Post-Breeding Dispersal - No particular dispersal direction or destination was evident in movements of individual murrelets after leaving PS, although some areas of concentration were noted. Five birds (#303, #362, #464, #844, and #863) appeared to disperse primarily to the north where Glacier Bay and Douglas Island were the most common destinations, while 9 birds (#404, #444, #543, #564, #622, #701, #744, #784, and #804) dispersed widely to the south, from Endicott Arm and lower Stephen's Passage south to Frederick Sound, Keku Straits, and Chatham Strait. The remaining 3 birds (#324, #883, and #983) were found both north and south of PS. Bird #324 made some extraordinary movements (Fig. 11) totaling 678 km (over-water distance) in 18 days, including travel from Gastineau Channel to Keku Straits (186 km in 4 days), Keku Straits to Glacier Bay (286 km in 1 day), and Glacier Bay to Endicott Arm (238 km in 1 day).

Glacier Bay had previously been identified as an important foraging area for murrelets during the breeding season in northern Southeast Alaska (Piatt and Naslund 1995, Agler et al. 1998, Whitworth et al. 2000), and in 2005, we demonstrated that some murrelets that breed as far south as PS disperse to the Glacier Bay area (Icy Straits and lower and mid Glacier Bay). All PS murrelets found in Glacier Bay were apparently dispersing birds, although surveys in Glacier Bay did not commence until well after most of radio-marked murrelets had definitively left PS for the season. We cannot discount the possibility that some birds made regular long-distance movements between PS and Glacier Bay while still attending PS.

Evaluation of Telemtery Tracking Methods - Despite inherent limitations of each tracking method, each appeared to be similarly effective at detecting the presence of radio-marked murrelets known to be in PS on a particular day. The data logger system provided continuous monitoring over the entire study period, but their restricted reception ranges (about 2.5 km) limited their utility as a monitoring tool. We noted several instances when strong signals detected at nearby boat survey stations were not detected concurrently at data logger stations, although many individual frequencies were detected by data loggers earlier or later in the day. Thus, while data loggers did not provide the continuous monitoring of presence or absence in PS as desired, useful data on daily presence or absence and movements within PS was obtained.

Higher totals of detections and radio-marked murrelets were recorded by the data logger inside PS (station B) compared to the mouth (station A). This pattern indicated that many signals were missed as marked murrelets flew past the mouth of the inlet. Similarly, over half (51%) of the marked birds located outside PS during aerial surveys were not detected at mouth of the inlet during their inbound or outbound flights. Greater reliability of station B was related partly to differences in topography between areas. The inlet constricts near station B where murrelets are funneled into a restricted area and are more likely to be detected, whereas the mouth of PS at station A is several km wider than the effective range of the receiver. Although the data loggers provided valuable data in 2005, stations placed in areas such as narrow inlets or stream courses traversed by several nesting birds would be more a suitable use for these systems.

Elapsed times of 5 min or less between consecutive detections for the same individual frequency at both data logger stations were recorded on 39 occasions, indicating that movements between the mouth and inlet were often quite rapid. Assuming that limited tests of reception range of the data logger systems was accurate (~2.5 km for radios on the water), maximum flight speeds for 4 birds detected within 1 minute at both stations were 60 km h^{-1} between station A and B1 (6 km over-water distance).

Boat and aerial surveys offered improvements in detection range and thus more reliable data in terms of confirmed presence or absence compared to data logger monitoring. However, boat and aerial surveys were severely limited by temporal or financial constraints. It is unlikely that marked birds present in PS went undetected during aerial or boat surveys, as transmitter detection ranges approached 15 km from the air and 3 to 4 km from the boat with much overlap between adjacent boat stations. However, instances of birds detected by data loggers on a given day but "missing" during other surveys earlier or later that same day did occur. These "missing" murrelets most likely were due to movements out of PS before or after detection by data loggers. We recorded several instances of murrelets first detected in PS by boat-based surveys or data

logger monitoring, then later detected far from PS during aerial surveys on the same day. Similar movements undoubtedly occurred into areas not covered by aerial surveys or on days when aerial surveys were not conducted.

We originally conducted boat surveys opportunistically to verify data logger monitoring. When limitations of the data logger system became evident we conducted more frequent boat surveys to maximize murrelet presence/absence data in PS. In 2006, if time allows, an intensive, standardized boat survey schedule, focusing on 1 or 2 birds at a time could yield more detailed activity patterns (as was the case with land and boat monitoring by Whitworth et al. [2000] in Auke Bay). Strategically placed data loggers (e.g., near active nests, 4 to 5 placed throughout PS) could also help monitor activity at nest sites and provide more details on flights in and out of PS. Sufficient funding for an increase in aerial survey effort will be necessary for future research designed to examine nesting habitat characteristics of murrelets from PS, because some or many birds visiting PS are likely nesting at considerable distances from the inlet.

Prey Species during the Chick-feeding Phase - During capture attempts, about 35-50% of murrelets encountered held single fish "crosswise in their bills" (Carter and Sealy 1987). Fish-holding behavior appeared to increase later in the night, possibly indicating that some prey were captured locally at night (although few were seen diving) or that some birds already with fish in their bills had arrived well after dark from other areas to sit on the water, potentially in preparation to flying further up the inlet to nests to feed chicks at or after first light. However, a few birds with fish also were noted flying out of the inlet after first light.

All three Capelin retrieved were large juveniles or first-year subadults smaller than the range of adult size (10-20 cm), reflecting spawning in fall 2004. The single Pacific Sandlance retrieved was a first-year subadult and smaller than the range of adult size (20-25 cm), reflecting spawning in spring 2004. The sizes and age classes of fish held by murrelets in PS were comparable to those reported in Barkley Sound, British Columbia (Carter 1984, Carter and Sealy 1987).

While Pacific Sandlance is one of the most common prey species for murrelets throughout their range, Capelin have been reported as prey only in Alaska (Vermeer et al. 1987, Burkett 1995). Capelin occur from the arctic to southern British Columbia and are abundant in Alaska and among the primary prey species for many seabird species (e.g., Sanger 1987a). Use of Capelin by murrelets has not been documented previously in Southeast Alaska or British Columbia, but larval and juvenile Capelin were major food items in murrelets collected at Chiniak Bay (Kodiak Island, AK) in December-April 1976-78 and Kachemak Bay, AK in January-April 1978 (Krasnow and Sanger 1982; Sanger 1983, 1987a,b). Simons (1980) reported the delivery of a large subadult or adult Capelin by an adult murrelet to its chick at a 1978 ground nest at East Amatuli Island in the Barren Islands. Fish retrieved from fish-holding murrelets in 2005 indicated that Capelin also are an important prey species in Southeast Alaska and larger size classes (i.e., subadults) of Capelin may be widely used for chick diet in Alaska.

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Table 1: Summary of Marbled Murrelet capture efforts in Port Snettisham, Alaska, June-July 2005.

Capture Night	# Captured	# Radio-marked	Capture Times
28-29 June	14	14	00:20 - 02:40
29-30 June	13	13	00:19 - 02:34
30-1 July	8[1]	5	00:00 - 02:45
4-5 July	9	0	23:56 - 01:43
11-12 July	1	0	23:57
Total	45	32	

[1]Total includes a recently fledged juvenile, captured but not banded or radio-marked.

Table 2: Summary of aerial-based radio telemetry survey effort and results for Marbled Murrelets in Port Snettisham, Alaska, June-August, 2005.

		Location		
Date	Time	Within Port Snettisham	Outside Port Snettisham	Total Murrelets
3 July	15:50-17:30	13	4	17
5 July	10:56-15:00	21	7	28
6 July	12:39-15:55	17	14	31
7 July	14:10-16:45	17	10	27
8 July	12:02-14:10	16	8	24
11 July	15:00-16:31	18	2	20
13 July[1]	11:51-12:30	4	1	5
20 July	12:13-15:27	8	7	15
25 July	14:18-16:47	Not surveyed	6	6
28 July	09:23-12:58	Not surveyed	3	3
29 July	09:00-12:42	3	4	7
2 August	07:50-12:40	Not surveyed	2	2
3 August	14:10-20:27	Not surveyed	7	7
4 August	13:31-21:15	Not surveyed	4	4
9 August	15:30-18:45	Not surveyed	2	2
		117	81	198

[1]Survey abandoned due to mechanical problems with aircraft.

Table 3: Summary of boat-based radio telemetry monitoring efforts and results for Marbled Murrelets in Port Snettisham, Alaska, 29 June-1 August, 2005.

Date	Time	# Stations Monitored	Total Murrelets
29 June[1]	16:00-18:30	7	9
30 June[1]	02:50-03:20	1	4
2 July[1]	00:55-02:30	6	14
4 July	01:34-04:43	5	18
	15:57-17:49	6	4
5 July	02:48-04:44	1	17
	18:34-23:15	3	20
6 July	00:06-01:15	2	12
	20:45-21:15	2	13
7 July	23:57-02:15	4	16
8 July	00:15-03:11	5	17
9 July	19:57-21:23	4	15
10 July	16:03-19:00	5	15
11 July	04:58-06:51	4	17
12 July	00:37-02:25	4	12
	10:54-12:15	3	6
13 July	23:45-01:30	4	15
14 July	00:15-02:20	3	12
	19:30-20:45	3	10
15 July	11:23-01:00	3	9
	22:43-23:59	3	8
16 July	14:53-16:00	3	9
18 July	17:45-20:32	6	10
19 July	15:54-18:16	5	7
21 July	12:11-13:43	4	8
22 July	05:18-08:26	5	9
	22:00-23:05	2	7
23 July[2]	18:11-18:50	2	2
24 July	04:10-08:38	5	7
	20:30-22:11	3	7
28 July	18:00-20:00	4	0
29 July	19:43-21:20	4	1
30 July	10:52-12:58	4	0
31 July	20:45-21:35	3	0
1 Aug	15:10-16:08	3	0

[1]Fixed stations not yet established during these surveys, coverage area approximate.
[2]Survey terminated due to low battery on receiver.

Table 4: Summary of detection histories for individual Marbled Murrelets captured and radio-marked at Port Snettisham (PS), Alaska, June-August 2005.

Bird #	Capture Date	Last Detection	Tracking Duration	Aerial Survey Detections			Data Logger Detections	
				Inside PS	Outside PS	Total	Detections	Days Detected
303	30 Jun	3 Aug	35 d	7	1	8	288	31
324	30 Jun	9 Aug	41 d	1	12	13	127	13
362	29 Jun	3 Aug	36 d	6	1	7	107	23
382	29 Jun	8 July	10 d	3	1	4	55	5
404*	30 Jun	4 Aug	36 d	3	6	9	86	12
423	30 Jun	24 Jul	25 d	7	0	7	102	19
444	1 Jul	29 Jul	29 d	3	3	6	9	3
464	29 Jun	28 Jul	30 d	6	1	7	124	19
503	29 Jun	26 Aug	59 d	7	2	9	482	45
524	1 Jul	25 Jul	25 d	0	4	4	0	0
543	30 Jun	6 Jul	7 d	0	1	1	0	0
564	29 Jun	6 Jul	8 d	0	1	1	27	5
583	1 Jul	11 Jul	11 d	6	0	6	62	9
603	29 Jun	14 Jul	16 d	5	1	6	28	11
622	30 Jun	20 Jul	21 d	1	2	3	15	3
643*	1 Jul	25 Jul	25 d	8	0	8	197	22
664	30 Jun	11 Jul	12 d	6	0	6	109	12
684	29 Jun	13 Jul	15 d	3	2	5	56	10
701*	29 Jun	29 Jul	31 d	0	8	8	9	3
744	29 Jun	20 Jul	22 d	6	1	7	37	13
762	30 Jun	6 Aug	38 d	4	2	6	153	21
784	29 Jun	25 Jul	27 d	0	3	3	9	2
804	30 Jun	4 Aug	36 d	4	1	5	171	23
823*	29 Jun	15 Jul	17 d	6	1	7	36	11
844	29 Jun	3 Aug	36 d	4	2	6	59	17
863	29 Jun	3 Aug	36 d	3	5	8	161	24
883	30 Jun	3 Aug	35 d	5	4	9	37	10
904	30 Jun	12 Jul	13 d	5	0	5	45	10
925	1 Jul	23 Jul	23 d	2	5	7	82	16
945*	29 Jun	11 Jul	13 d	5	0	5	28	9
964*	30 Jun	7 Jul	8 d	0	3	3	13	3
983*	30 Jun	4 Aug	36 d	1	8	9	18	5

*Indicates a Marbled Murrelet holding a fish when captured.

Table 5: Summary of data logger telemetry monitoring effort and results for Marbled Murrelets in Port Snettisham, Alaska, 29 June-26 August, 2005. Data includes the daily number of murrelets detected (Total # birds)) at either data logger station, and the daily number of detections (Det.) and murrelets (#) detected at each station. Station A was located near the mouth of Port Snettisham, while station B was located at Sentinel Point until 6 July and relocated to Fannie Island afterwards.

Date	Total # birds	Station A		Station B		Date	Total # birds	Station A		Station B	
		Det.	#	Det.	#			Det.	#	Det.	#
29 June	11	198	11	-	-	29 July	4	4	3	47	4
30 June	15	97	15	4	3	30 July	2	1	1	2	1
1 July	23	60	16	53	15	31 July	1	0	0	8	1
2 July	17	26	12	70	11	1 Aug	2	1	1	17	2
3 July	20	30	11	56	16	2 Aug	1	0	0	1	1
4 July	15	10	6	46	12	3 Aug	1	0	0	11	1
5 July	16	33	15	30	11	4 Aug	2	2	1	19	2
6 July	13	12	6	37	13	5 Aug	2	0	0	40	2
7 July	17	21	9	94	14	6 Aug	2	3	1	5	1
8 July	20	19	10	84	16	7 Aug	1	2	1	3	1
9 July	14	16	7	82	14	8 Aug	1	2	1	13	1
10 July	18	14	4	50	15	9 Aug	1	2	1	14	1
11 July	20	31	12	69	13	10 Aug	1	2	1	1	1
12 July	15	38	12	73	12	11 Aug	0	0	0	0	0
13 July	16	6	6	69	14	12 Aug	1	0	0	10	1
14 July	12	6	2	84	11	13 Aug	1	0	0	1	1
15 July	13	7	3	73	12	14 Aug	1	2	1	1	1
16 July	11	5	4	69	11	15 Aug	1	5	1	3	1
17 July	10	43	4	85	10	16 Aug	1	2	1	3	1
18 July	10	15	8	46	9	17 Aug	1	1	1	0	0
19 July	9	19	6	24	8	18 Aug	1	3	1	38	1
20 July	7	11	4	36	6	19 Aug	1	3	1	39	1
21 July	11	12	5	68	10	20 Aug	1	1	1	2	1
22 July	8	3	2	46	8	21 Aug	1	2	1	2	1
23 July	6	4	2	65	6	22 Aug	1	3	1	1	1
24 July	7	0	0	37	7	23 Aug	0	0	0	0	0
25 July	5	0	0	32	5	24 Aug	1	1	1	17	1
26 July	6	2	1	37	6	25 Aug	1	0	0	3	1
27 July	5	2	2	60	5	26 Aug	1	1	1	2	1
28 July	4	20	3	47	4						

Table 6: Summary of boat-based radio telemetry survey results at nine fixed stations in Port Snettisham, Alaska, July-August 2005.

Station #	# Surveys	# Days Surveyed (Dates)	# Murrelets (mean ± sd; range)
1	4	3 (4, 8, 18 Jul)	5.3 ± 6.4; 0-14
2	20	17 (4, 6-15, 18, 22, 24, 28-29, 31 Jul)	5.0 ± 4.4; 0-13
3	2	2 (4, 8 Jul)	6.5 ± 9.2; 0-13
4	16	15 (4, 10-15, 18-19, 23-24, 28-30 Jul; 1 Aug)	3.3 ± 3.7; 0-12
5	14	8 (4-5, 9, 14-15, 22, 24, 31 Jul)	7.1 ± 4.2; 0-13
6	25	21 (4-5, 7-8, 10-16, 18-19, 21-24, 28-30 Jul; 1 Aug)	5.2 ± 3.6; 0-13
7	20	14 (5-10, 14-15, 19, 21-22, 24, 30-31 Jul)	6.8 ± 5.5; 0-20
8	21	18 (5, 7, 9-12, 14-16, 18-19, 21-22, 24, 28-30 Jul; 1 Aug)	4.1 ± 3.9; 0-13
9	3	3 (6, 18, 24 Jul)	3.0 ± 2.0; 1-5

Table 7: Comparison of aerial survey, boat-based survey, and data logger monitoring results for Marbled Murrelets detected at the mouth of Port Snettisham, Alaska (includes detections from all aerial surveys at the mouth, data logger station A, and boat stations 1-3). Data are presented only for days when all three survey/monitoring methods or boat-data logger monitoring was employed.

	Survey Methods Employed	
Murrelets detected by:	Aerial-Boat-Data logger[1]	Boat-Data logger[2]
Aerial only	1 (1%)	-
Boat only	3 (3%)	25 (12%)
Data logger only	8 (7%)	35 (17%)
Aerial-Boat	13 (12%)	-
Aerial-Data logger	8 (7%)	-
Boat-Data logger	4 (4%)	141 (70%)
Aerial-Boat-Data logger	70 (65%)	-
Total Murrelets detected	107	201
Murrelets not detected by:	Aerial-Boat-Data logger[1]	Boat-Data logger[2]
Aerial	15 (14%)	-
Boat	17 (16%)	35 (17%)
Data logger	17 (16%)	25 (12%)

[1]Surveys/monitoring conducted on 5, 6, 7, 8, 11 and 29 July.
[2]Surveys/monitoring conducted on 2, 4, 9, 10, 12, 13, 14, 15, 16, 18, 19, 21, 22 and 24 July.

Table 8: Temporal distribution of Marbled Murrelet detections at data logger stations A and B in Port Snettisham, Alaska, in July-August 2005.

Time	Station A		Station B	
	# Detections	% Total	# Detections	% Total
00:00-02:00	42	9	112	6
02:00-04:00	133	30	217	11
04:00-06:00	44	10	203	11
06:00-08:00	23	5	196	10
08:00-10:00	13	3	174	9
10:00-12:00	38	8	116	6
12:00-14:00	9	2	154	8
14:00-16:00	7	2	132	7
16:00-18:00	1	0	131	7
18:00-20:00	12	3	150	8
20:00-22:00	48	11	224	12
22:00-24:00	78	17	120	6
	448		1929	

Table 9: Temporal distribution of Marbled Murrelet movements into and out of Port Snettisham, Alaska, as determined by detections at data logger stations A and B in July-August 2005.

Time	Into Port Snettisham		Out of Port Snettisham	
	# Detections	% Total	# Detections	% Total
00:00-02:00	7	9	5	10
02:00-04:00	45	55	3	6
04:00-06:00	9	11	4	8
06:00-08:00	5	6	2	4
08:00-10:00	4	5	1	2
10:00-12:00	1	1	2	4
12:00-14:00	1	1	0	0
14:00-16:00	1	1	0	0
16:00-18:00	0	0	0	0
18:00-20:00	1	1	3	6
20:00-22:00	3	4	6	13
22:00-24:00	5	6	22	46
	82		48	

Table 10: Duration (days) of absences for Marbled Murrelets which departed and returned to Port Snettisham, Alaska, during June-August 2005[1].

Duration of Absence	Number of Occurrences	% Occurrences
1 day	25	53
2 days	11	23
3 days	5	11
4 days	2	4
5 days	0	0
6 days	2	4
7 days	1	2
8 days	0	0
9 days	1	2

[1] Illustrated periods of time some birds were absent from PS. We could have missed some returning birds.

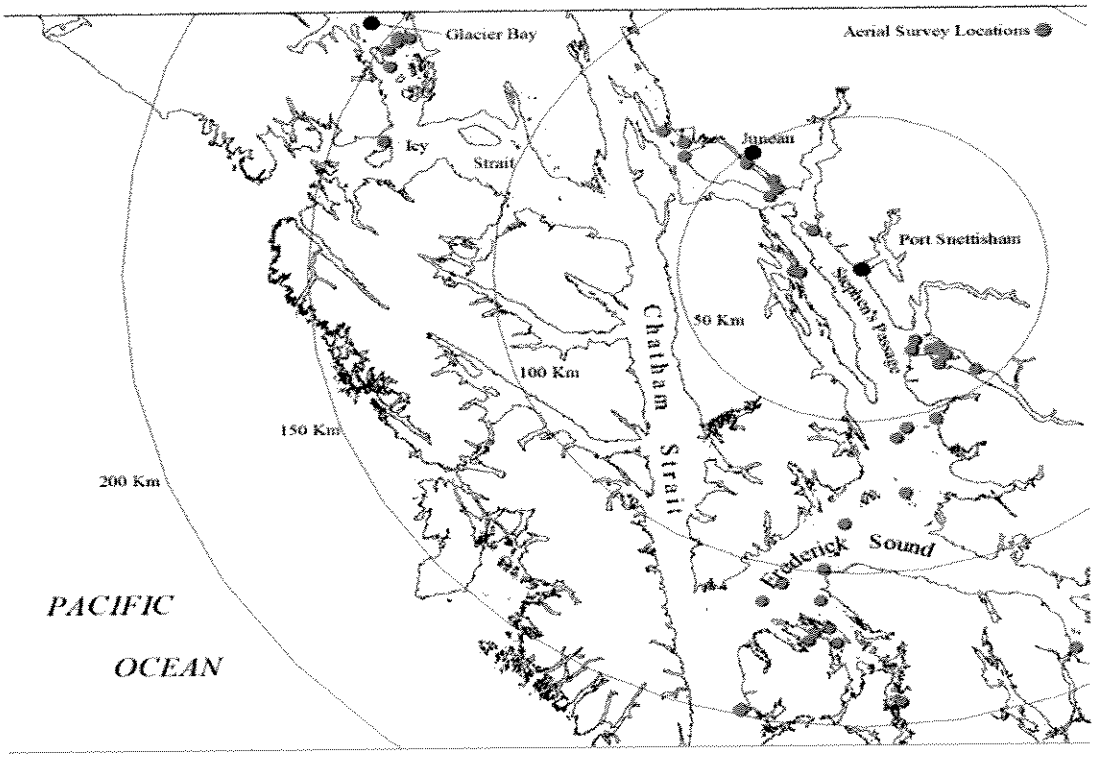


Figure 1. Southeast Alaska study area and location of aerial surveys for Marbled Murrelets, 2005.

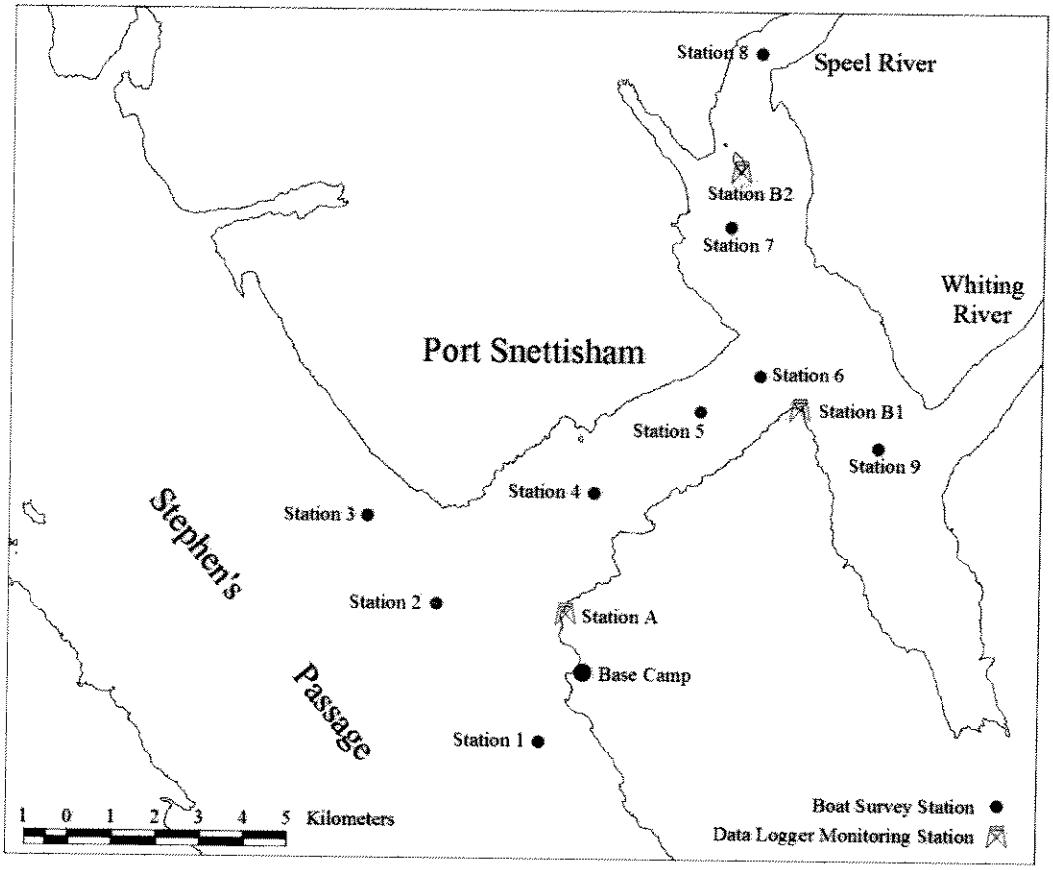


Figure 2. Port Snettisham study area with locations of data logger stations (A, B1 and B2) and boat survey stations (1-9), Southeast Alaska, 2005.

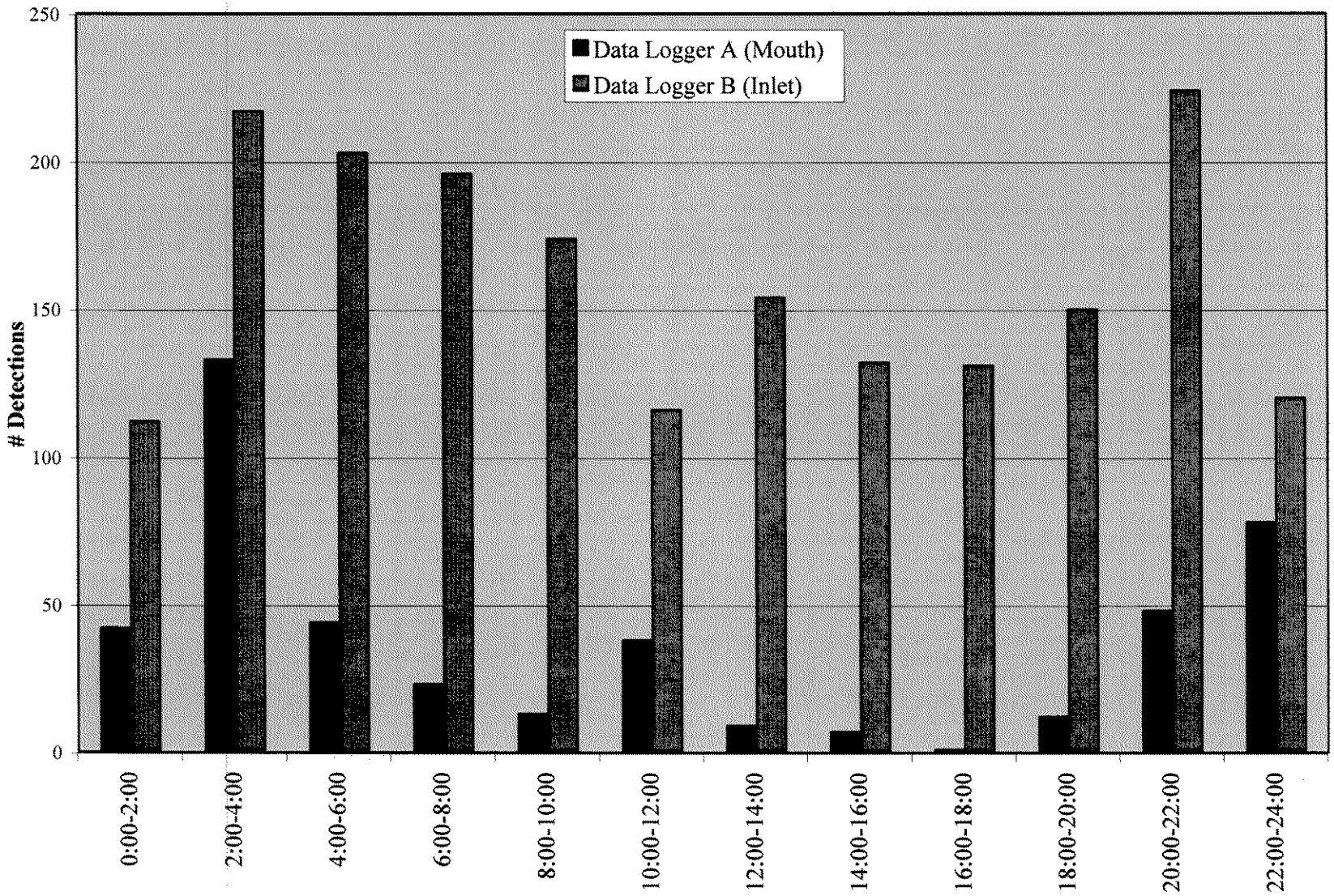


Figure 3. Temporal distribution of Marbled Murrelet detections at data logger stations in Port Snettisham, Alaska, June-August 2005.

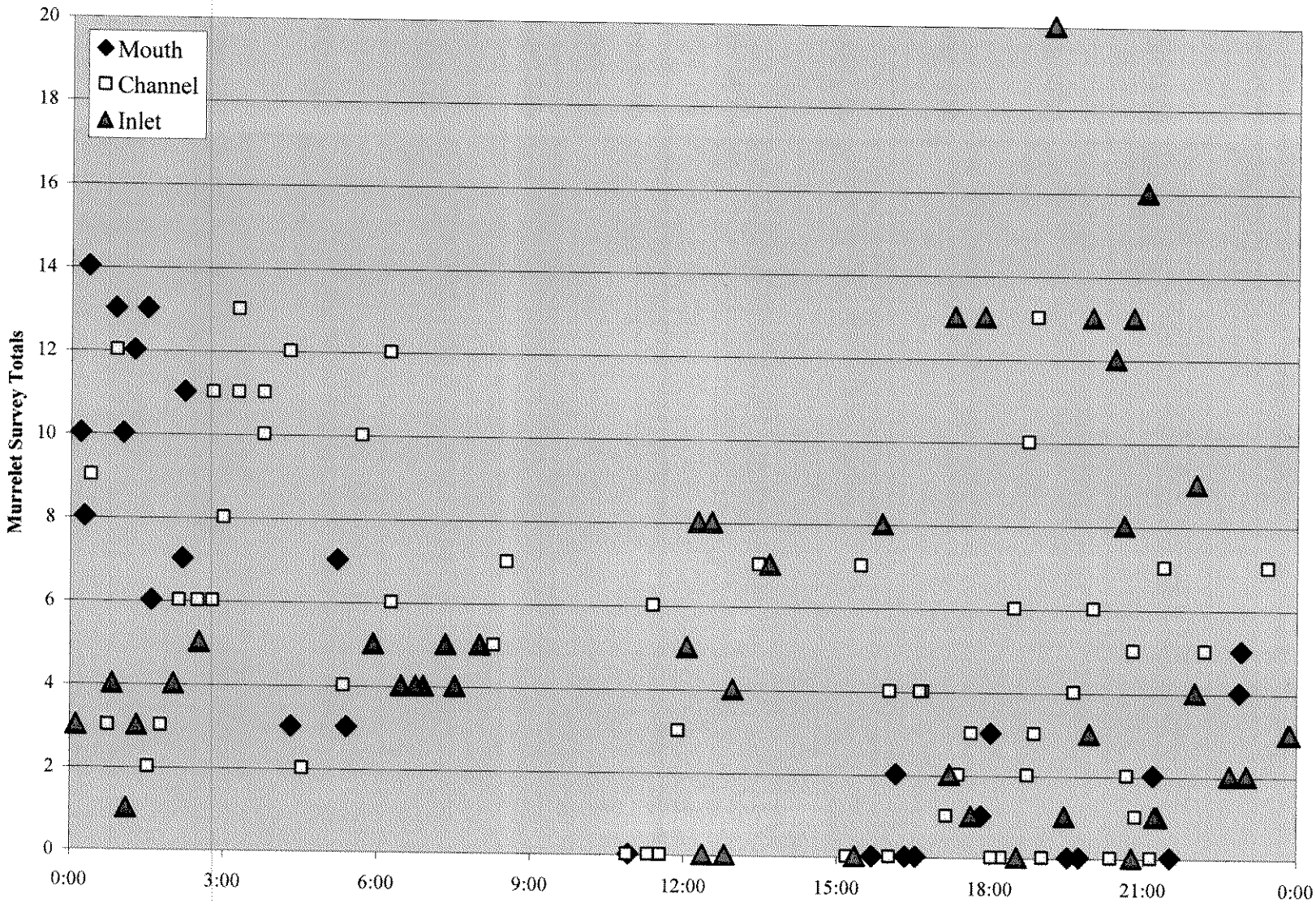


Figure 4. Daily trends in Marbled Murrelet numbers at boat-based survey stations in Port Snettisham, Alaska, June-August 2005.

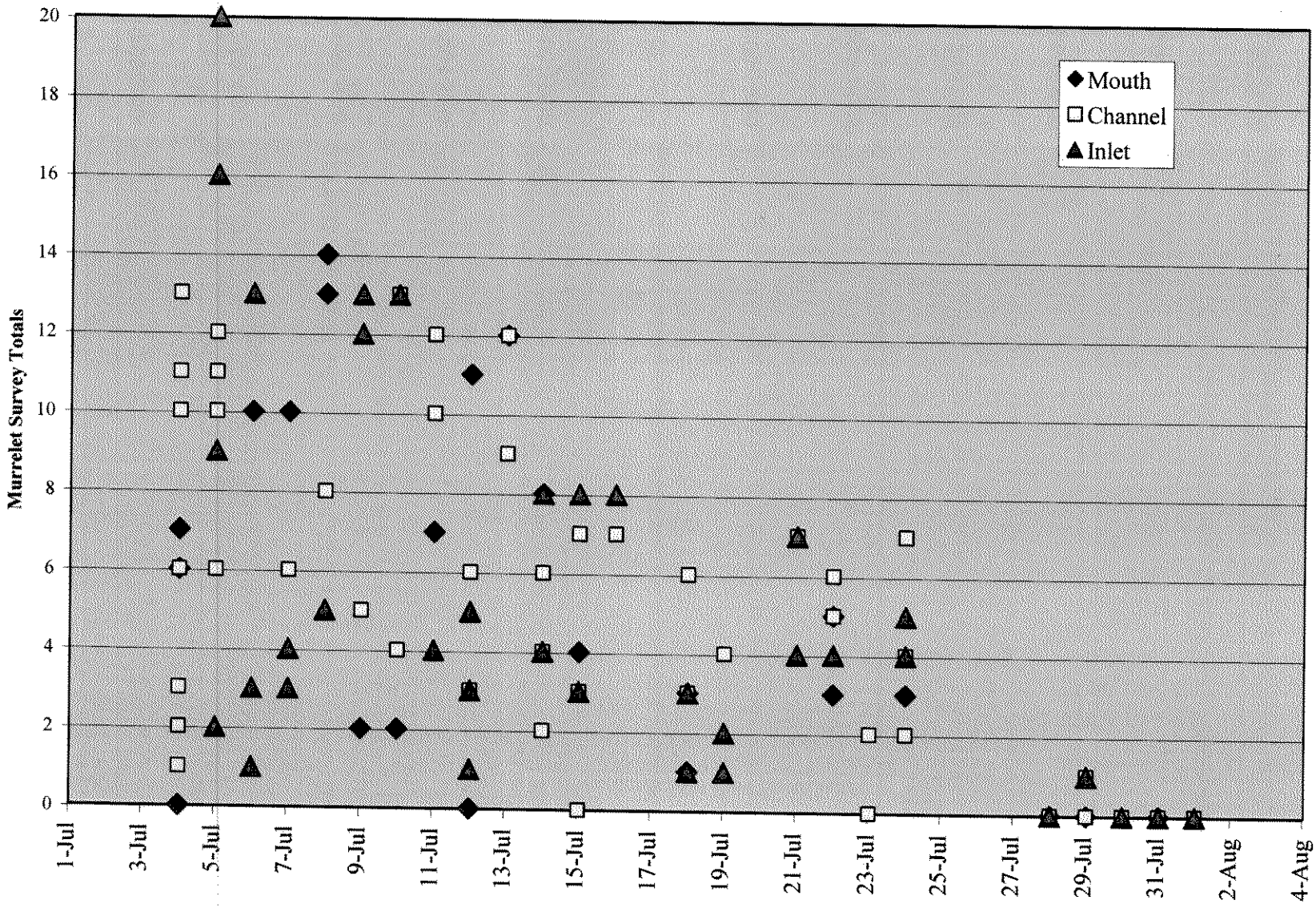


Figure 5. Seasonal trends in Marbled Murrelet numbers at boat-based survey stations in Port Snettisham, Alaska, June-August, 2005.

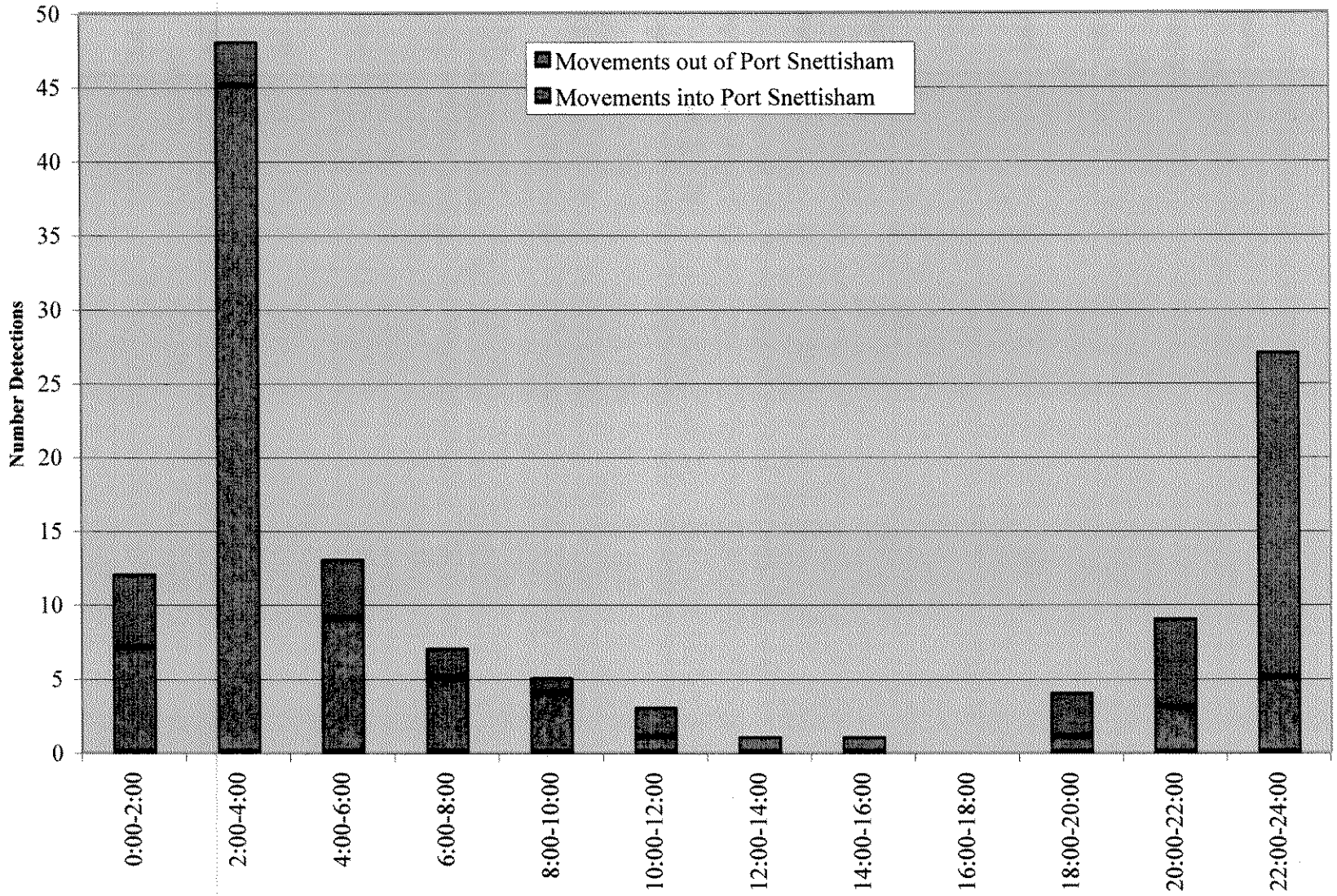


Figure 6. Temporal distribution of Marbled Murrelet movements in Port Snettisham, Alaska as determined from data logger detections, June-August 2005.

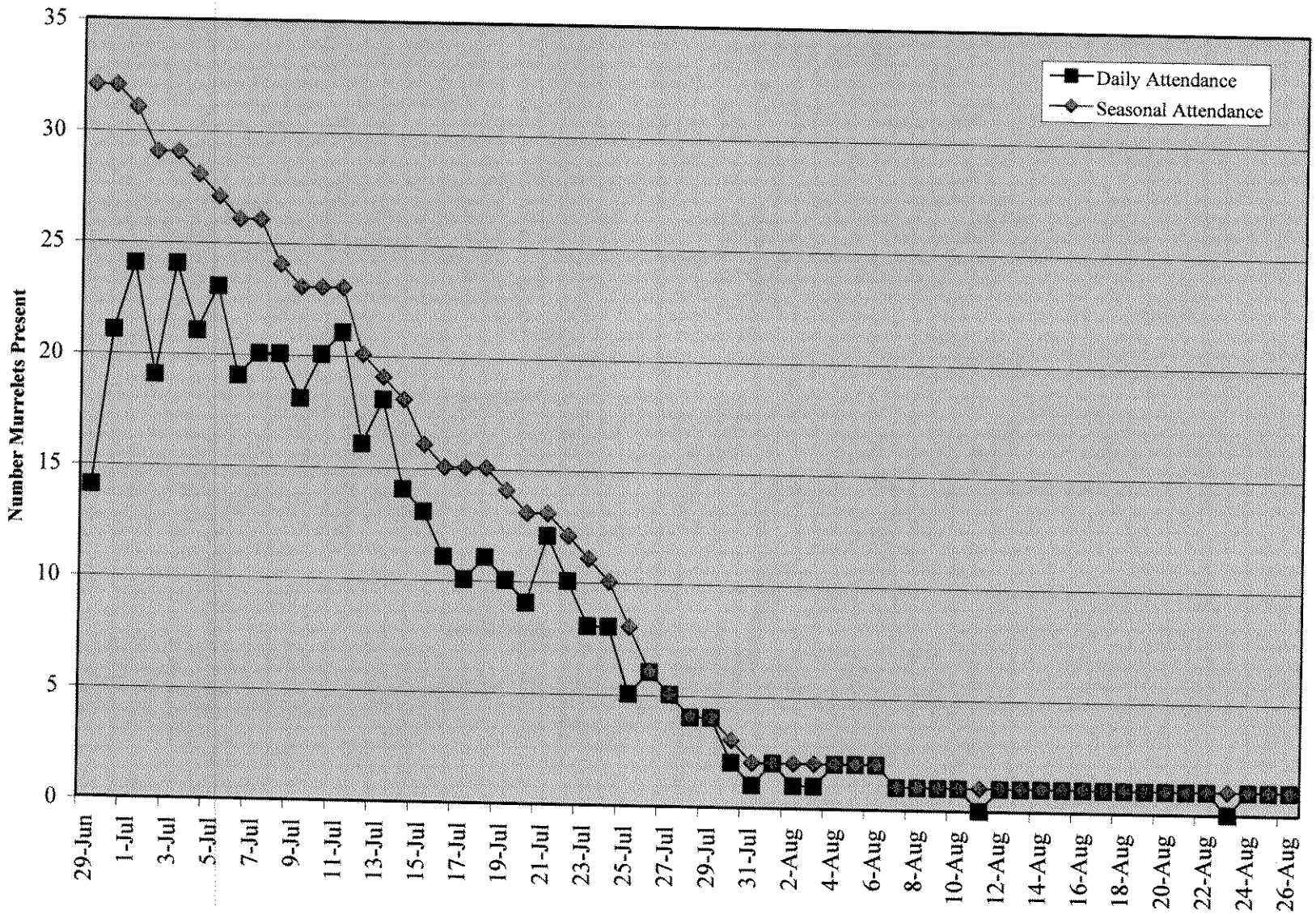


Figure 7. Daily and seasonal attendance patterns for Marbled Murrelets in Port Snettisham, Alaska, June-August 2005.

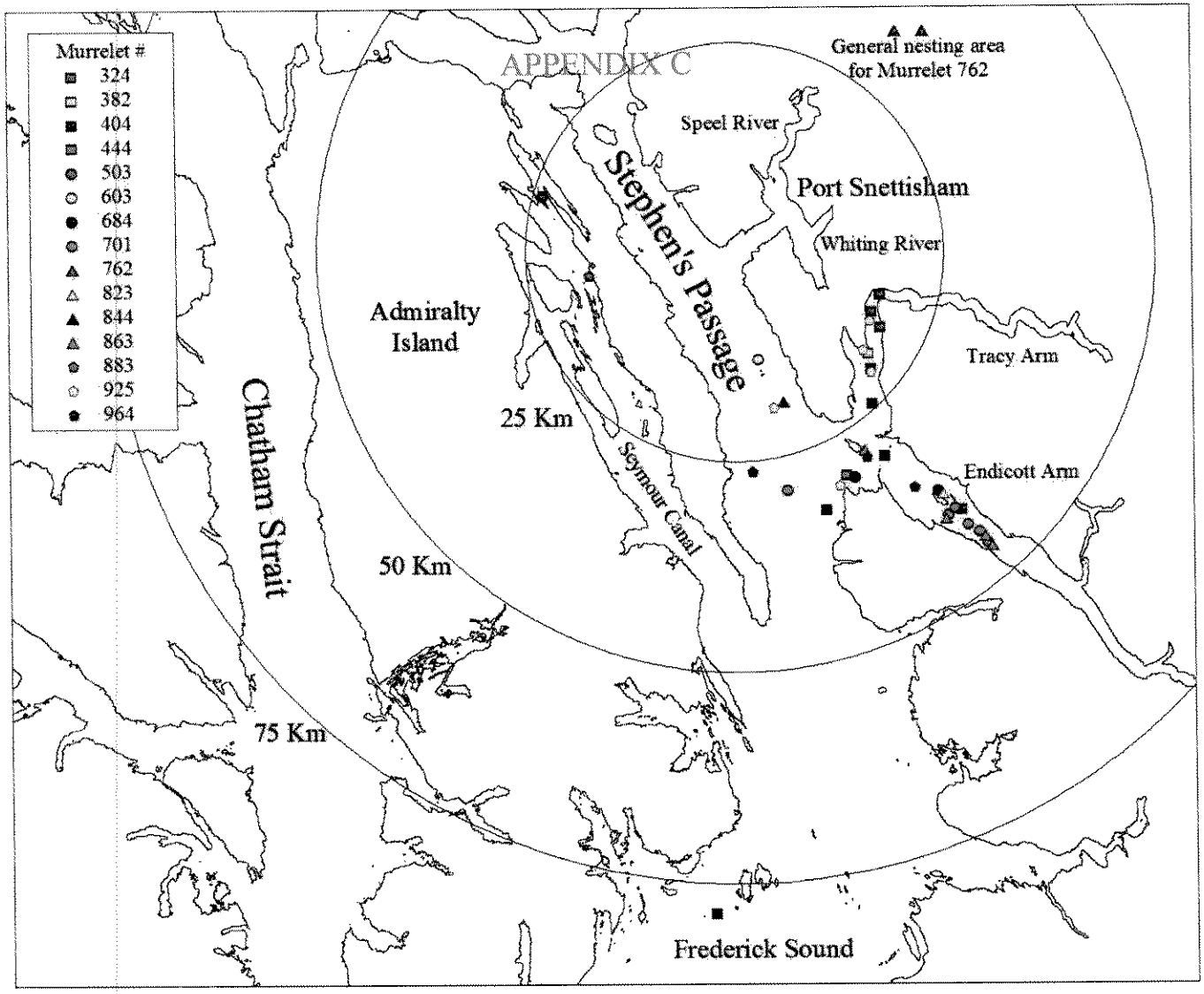


Figure 8. Aerial survey locations outside Port Snettisham for radio-marked Marbled Murrelets during the period individuals were detected returning to the inlet.

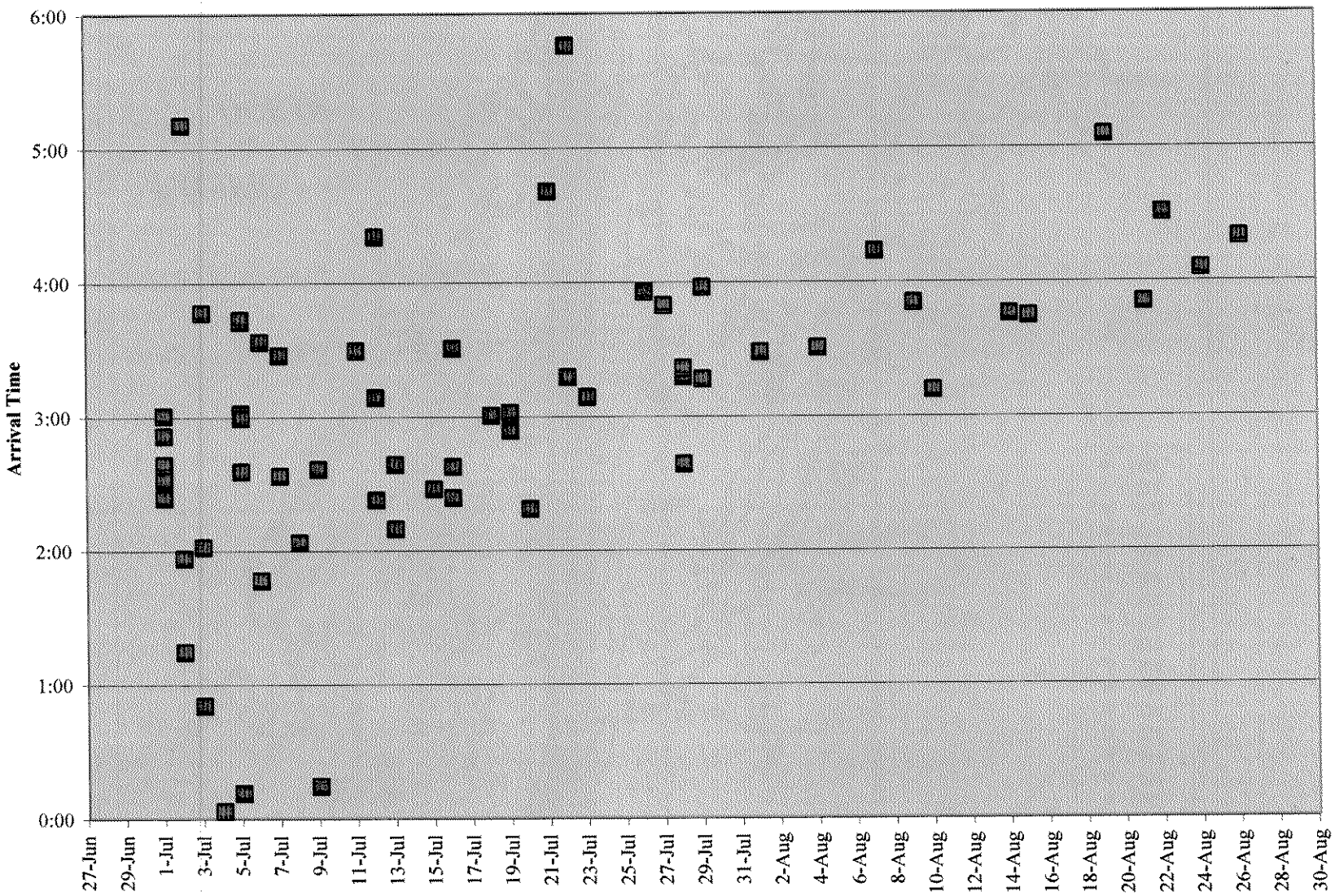


Figure 9. Morning arrival times for Marbled Murrelets during inbound flights to Port Snettisham, Alaska as detemined from data logger detections, July-August 2005.

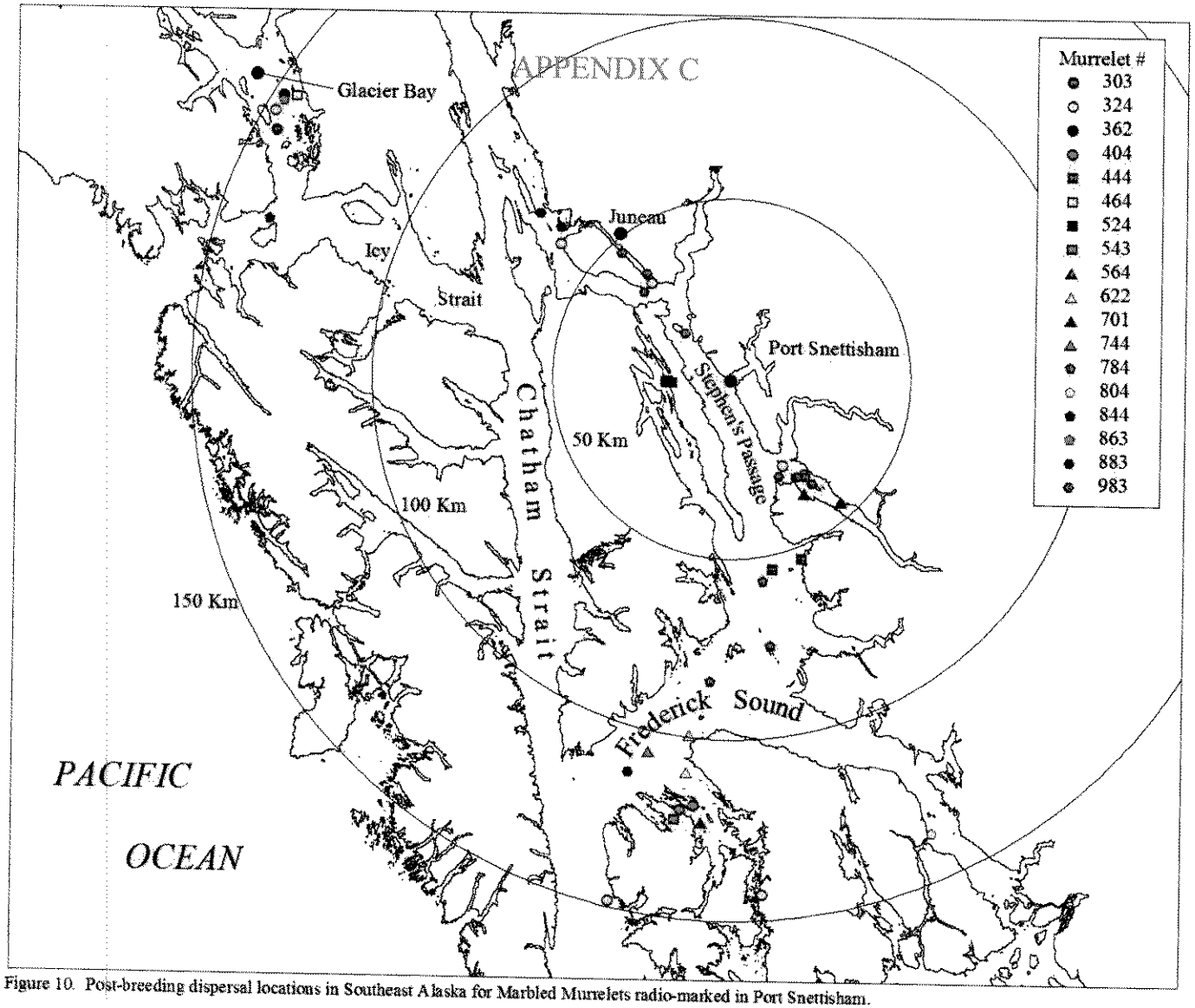
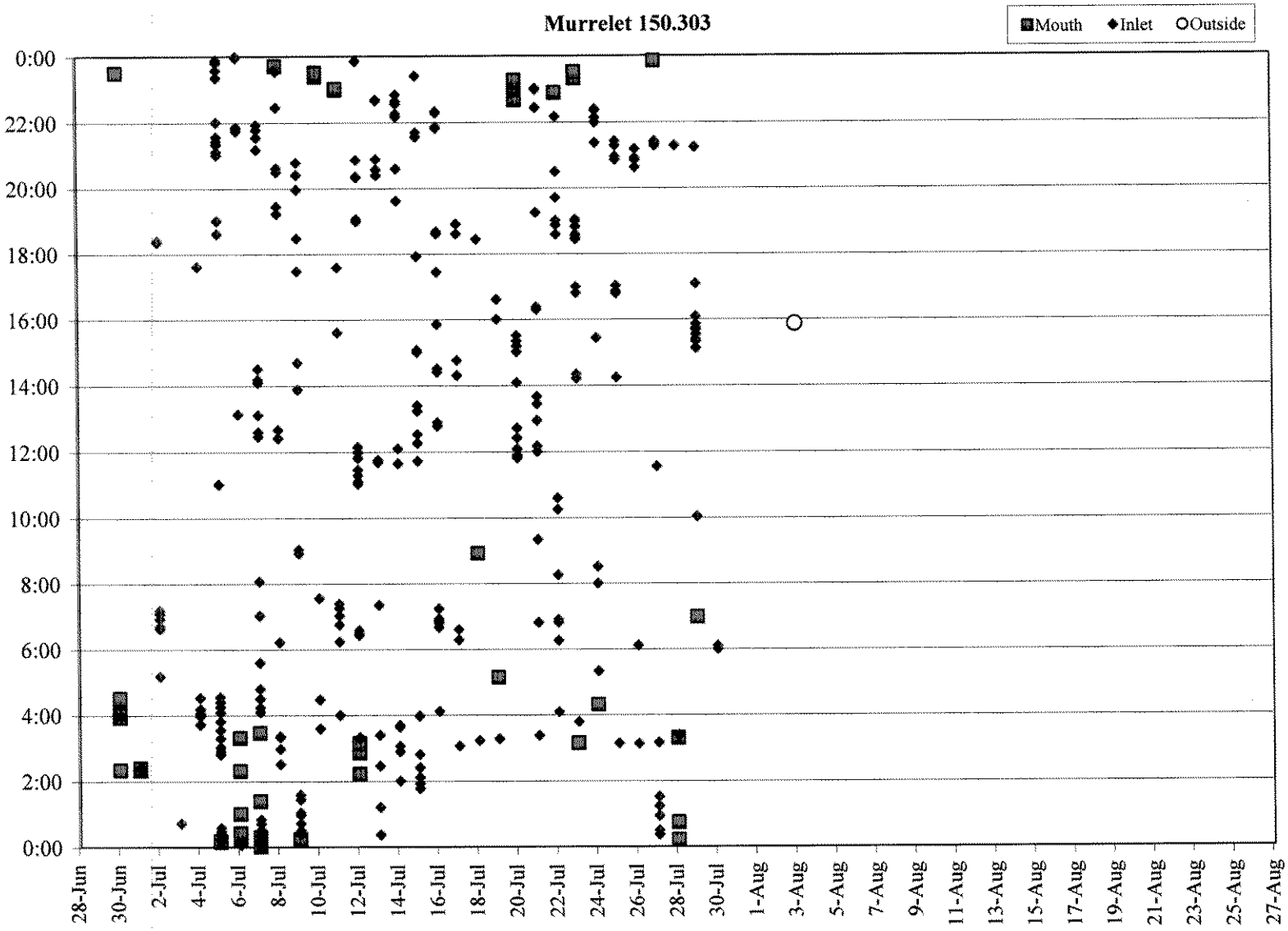


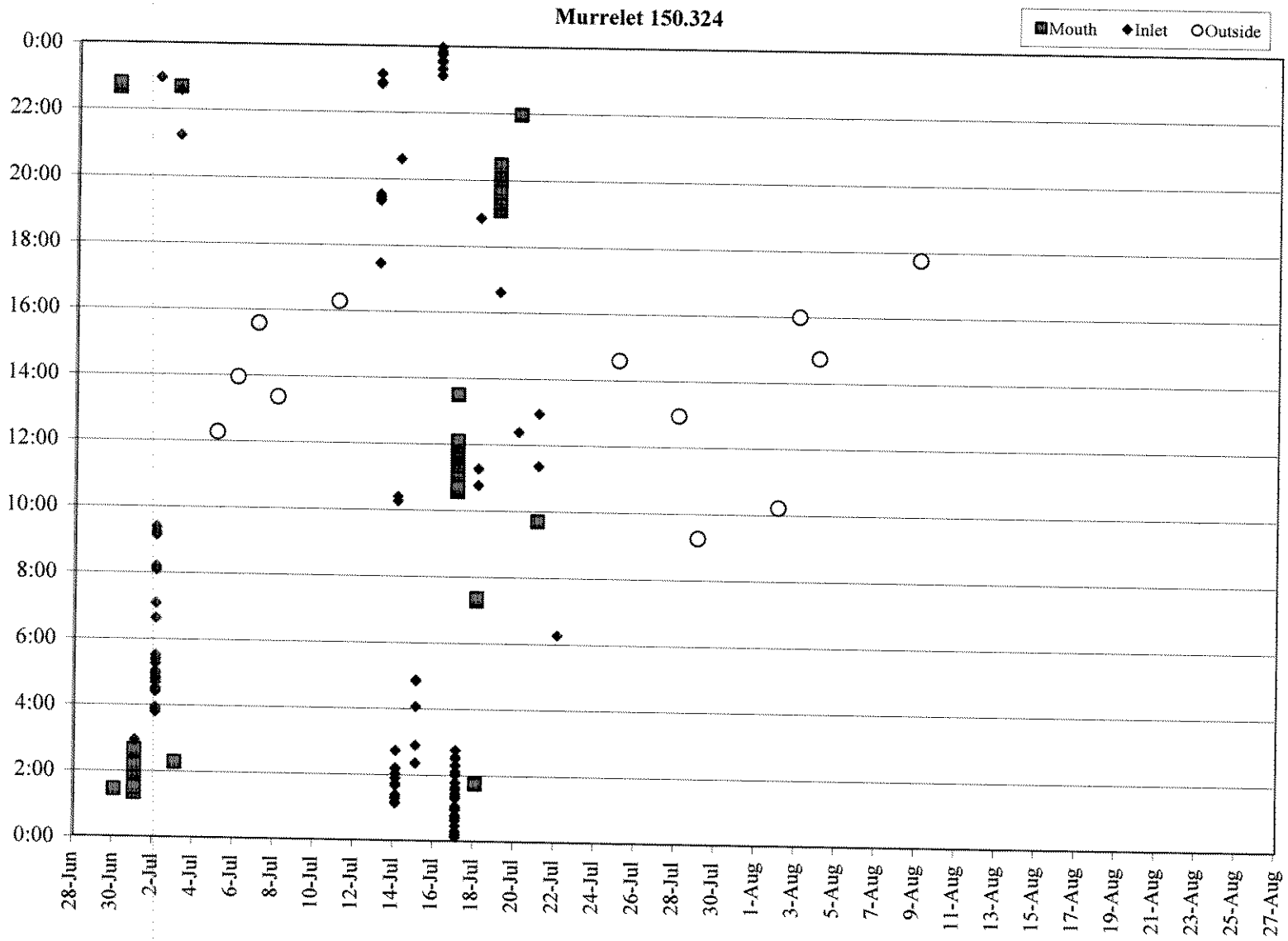
Figure 10. Post-breeding dispersal locations in Southeast Alaska for Marbled Murrelets radio-marked in Port Snettisham.

APPENDIX C



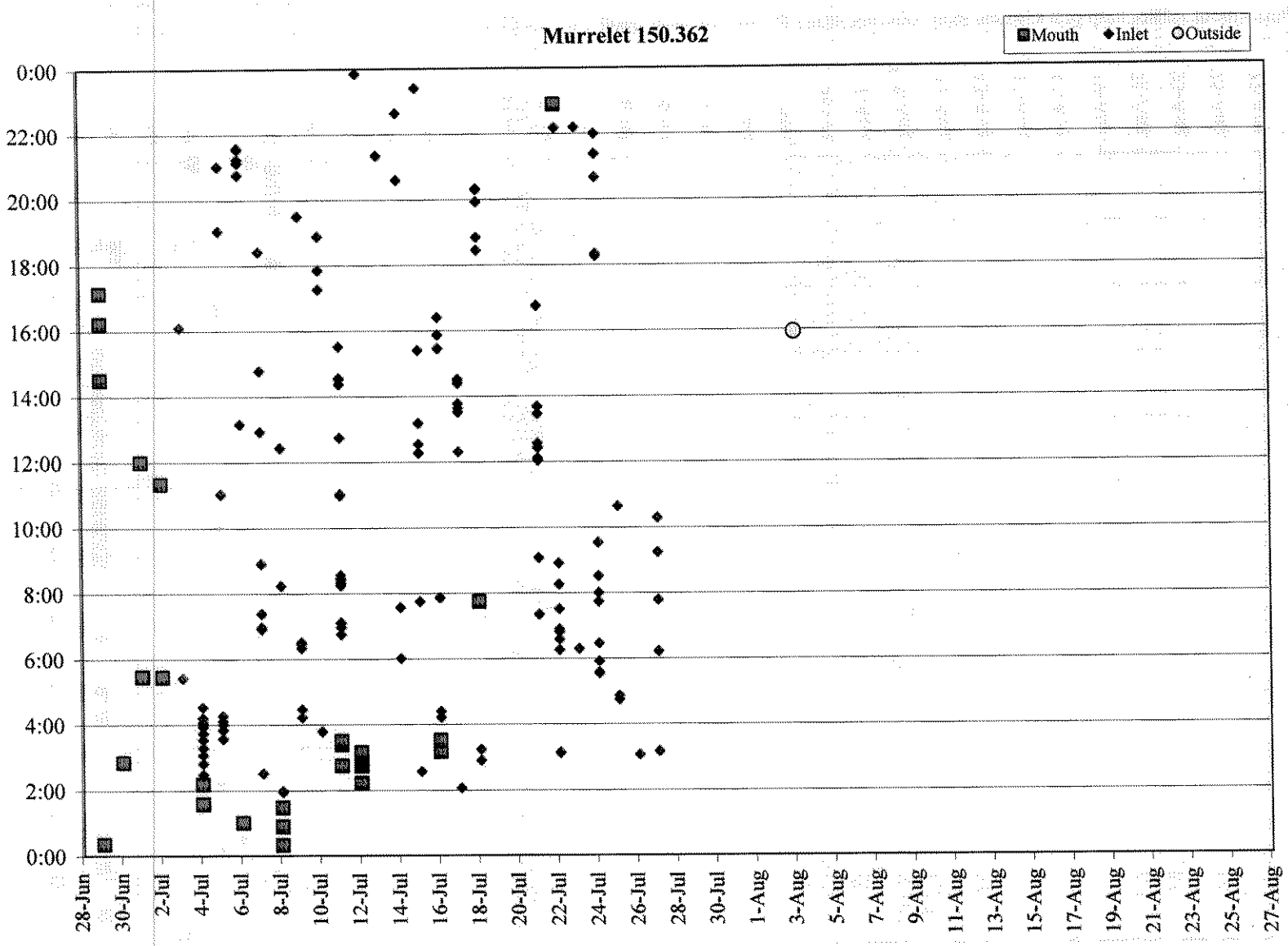
Appendix 1.1. Tracking history for Marbled Murrelet 150.303. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



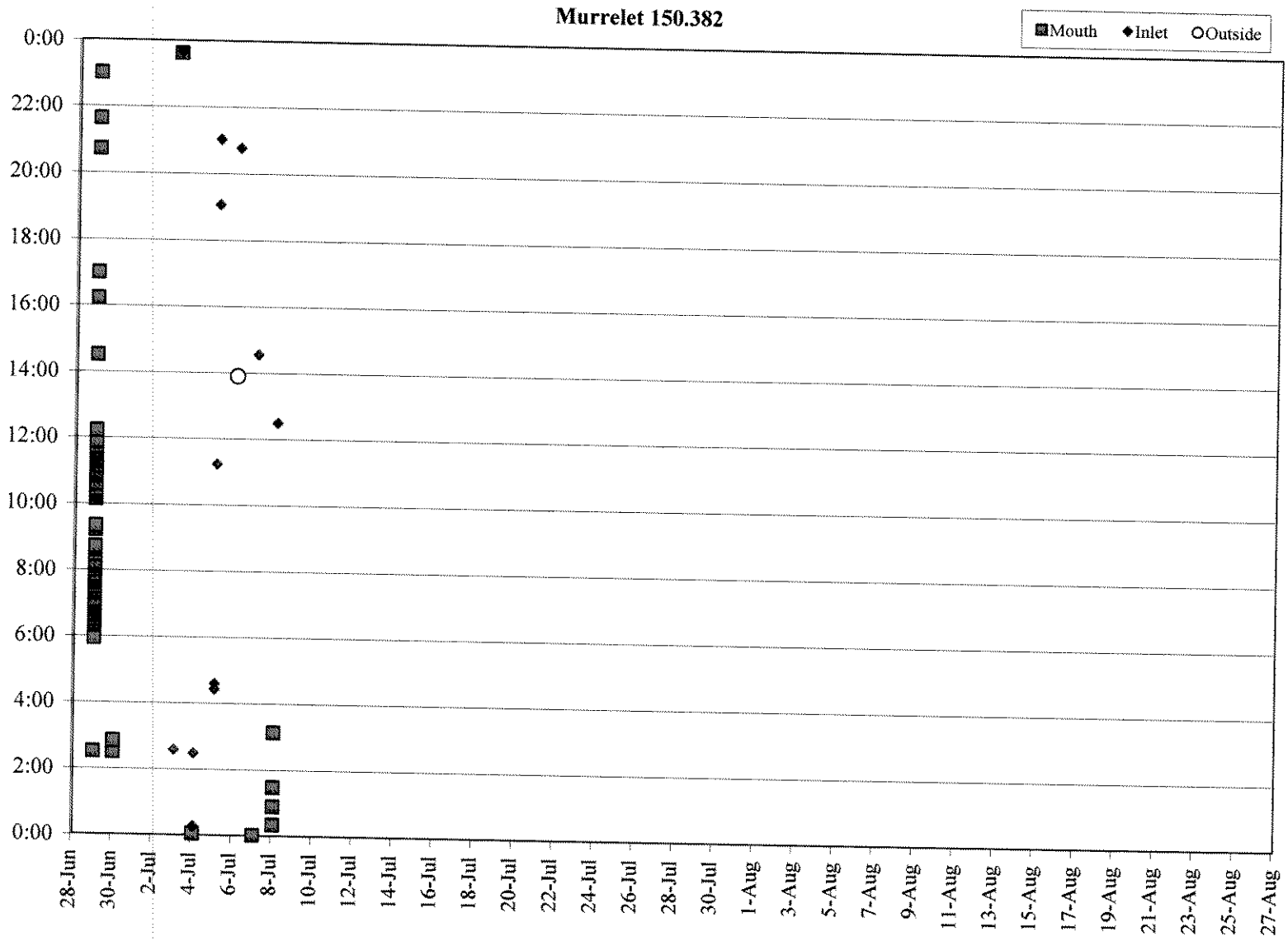
Appendix 1.2. Tracking history for Marbled Murrelet 150.324. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



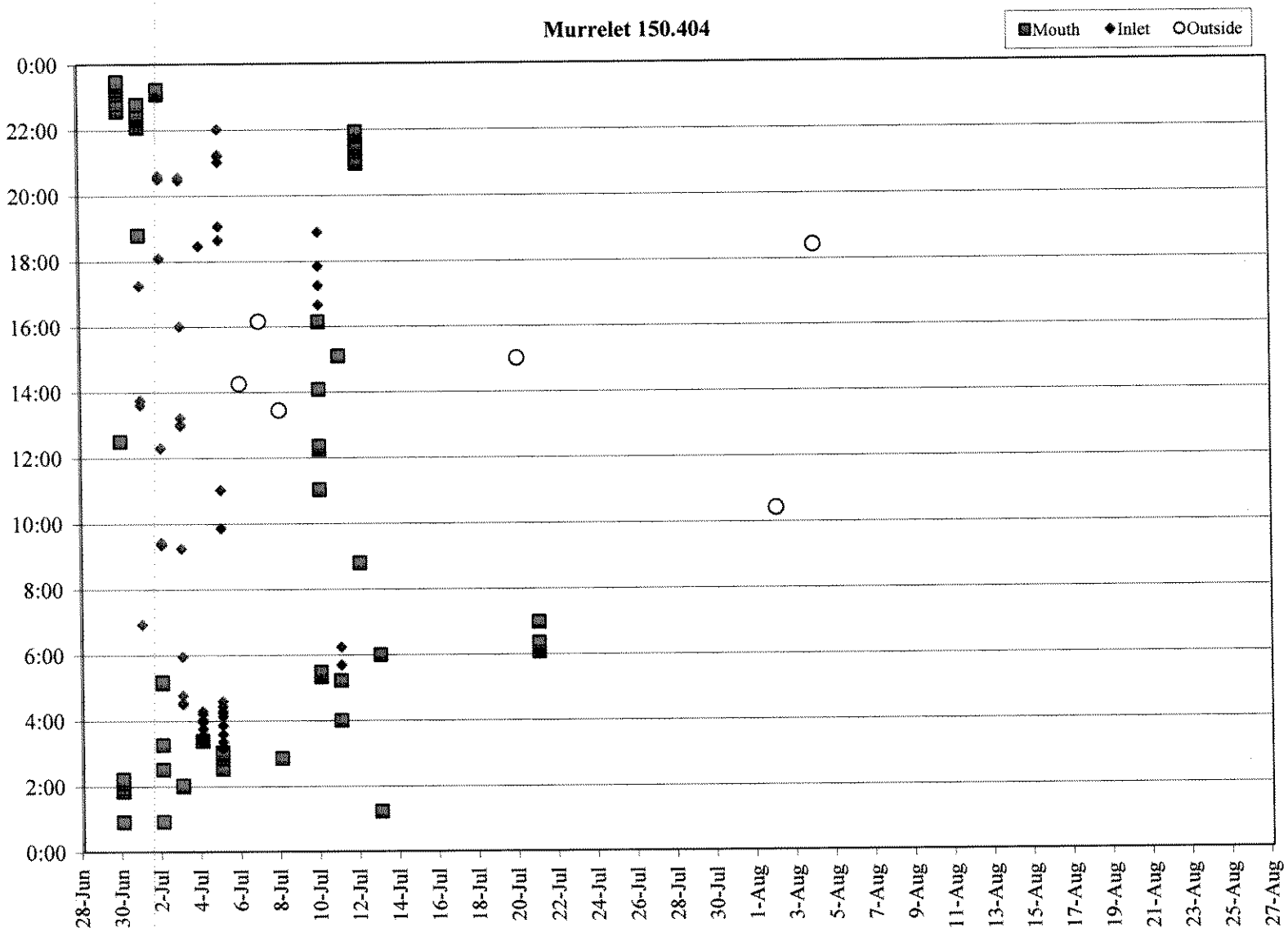
Appendix 1.3. Tracking history for Marbled Murrelet 150.362. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



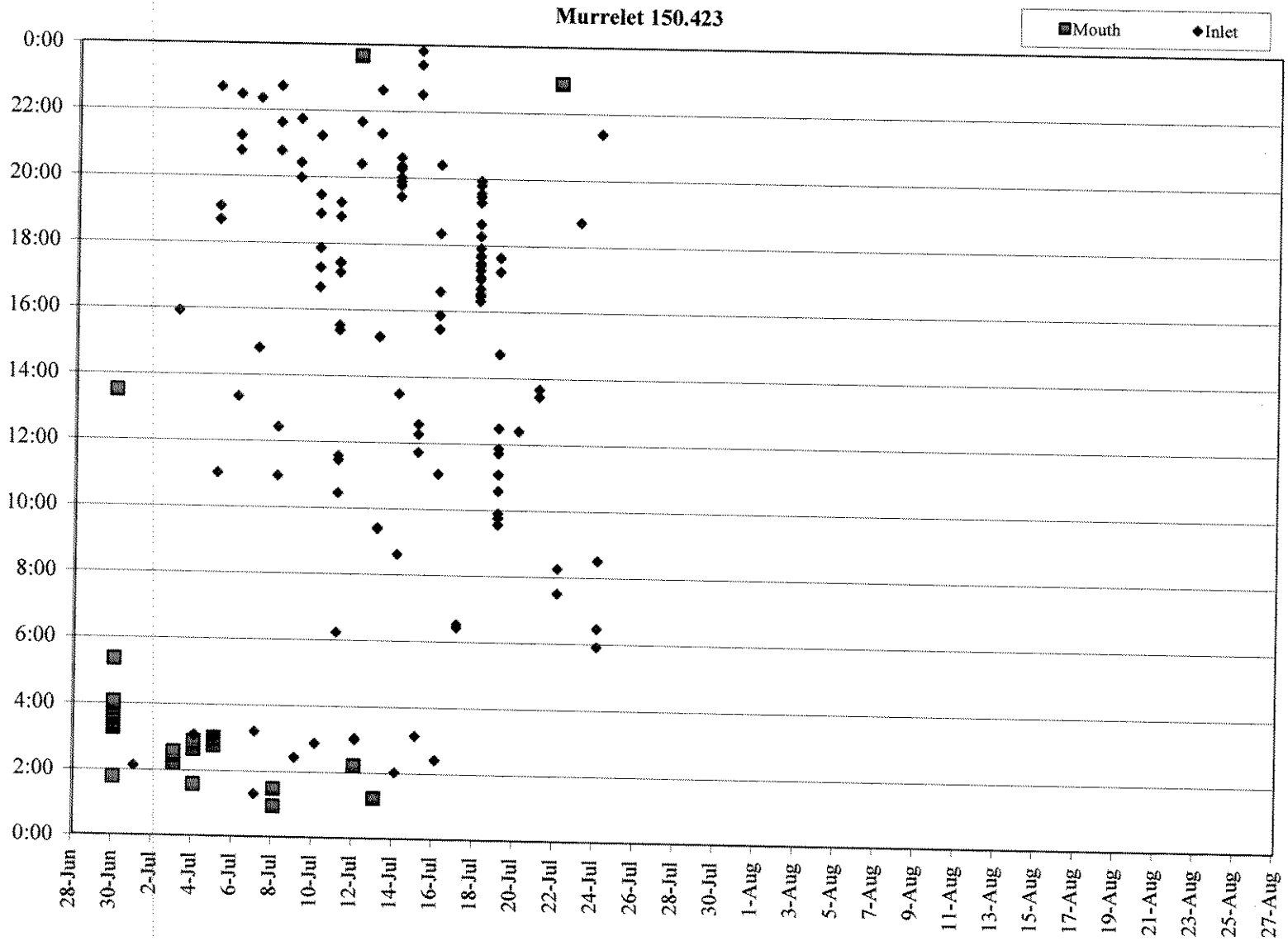
Appendix 1.4. Tracking history for Marbled Murrelet 150.382. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



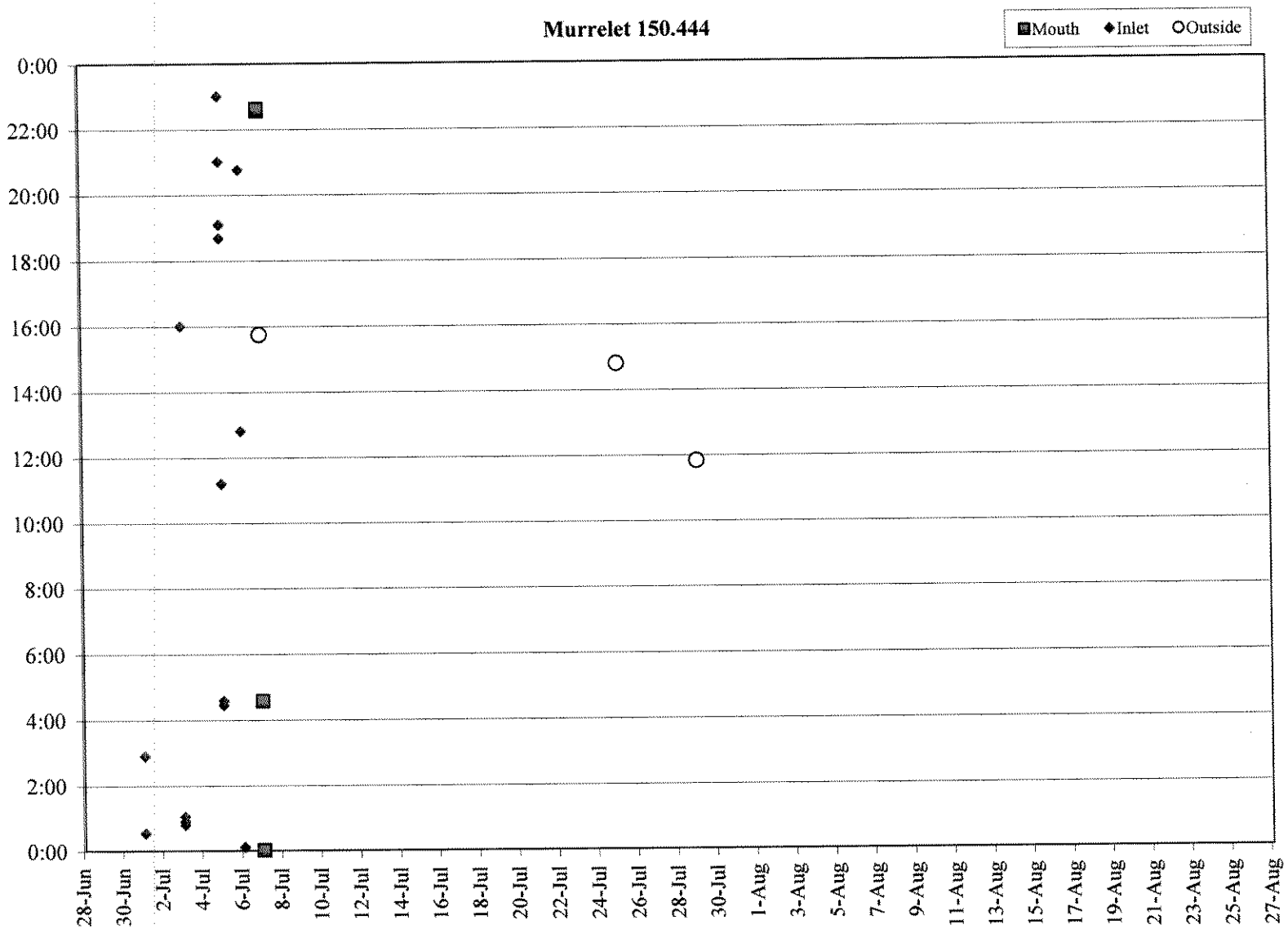
Appendix 1.5. Tracking history for Marbled Murrelet 150.404. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

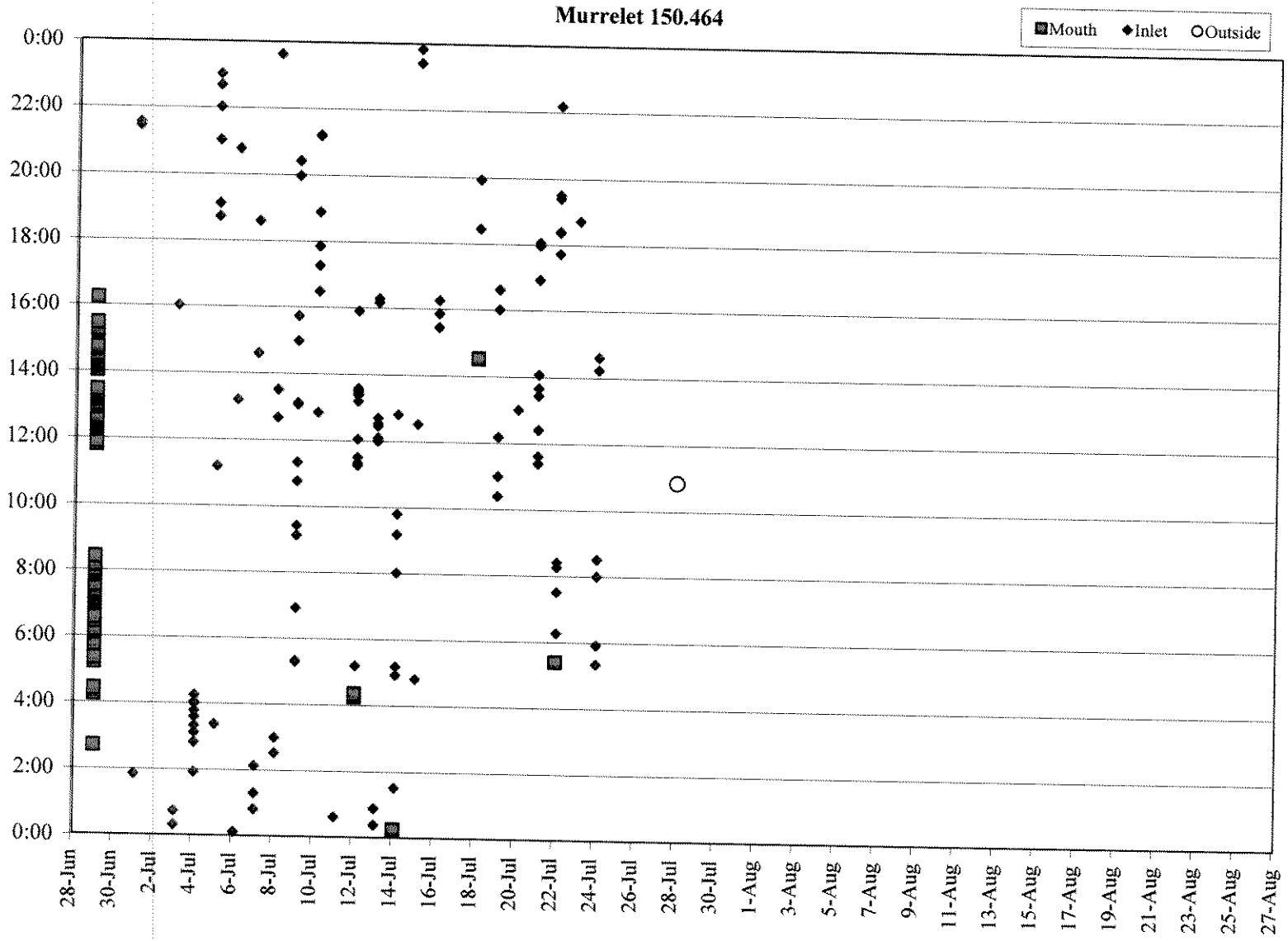


Appendix 1.6. Tracking history for Marbled Murrelet 150.423. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

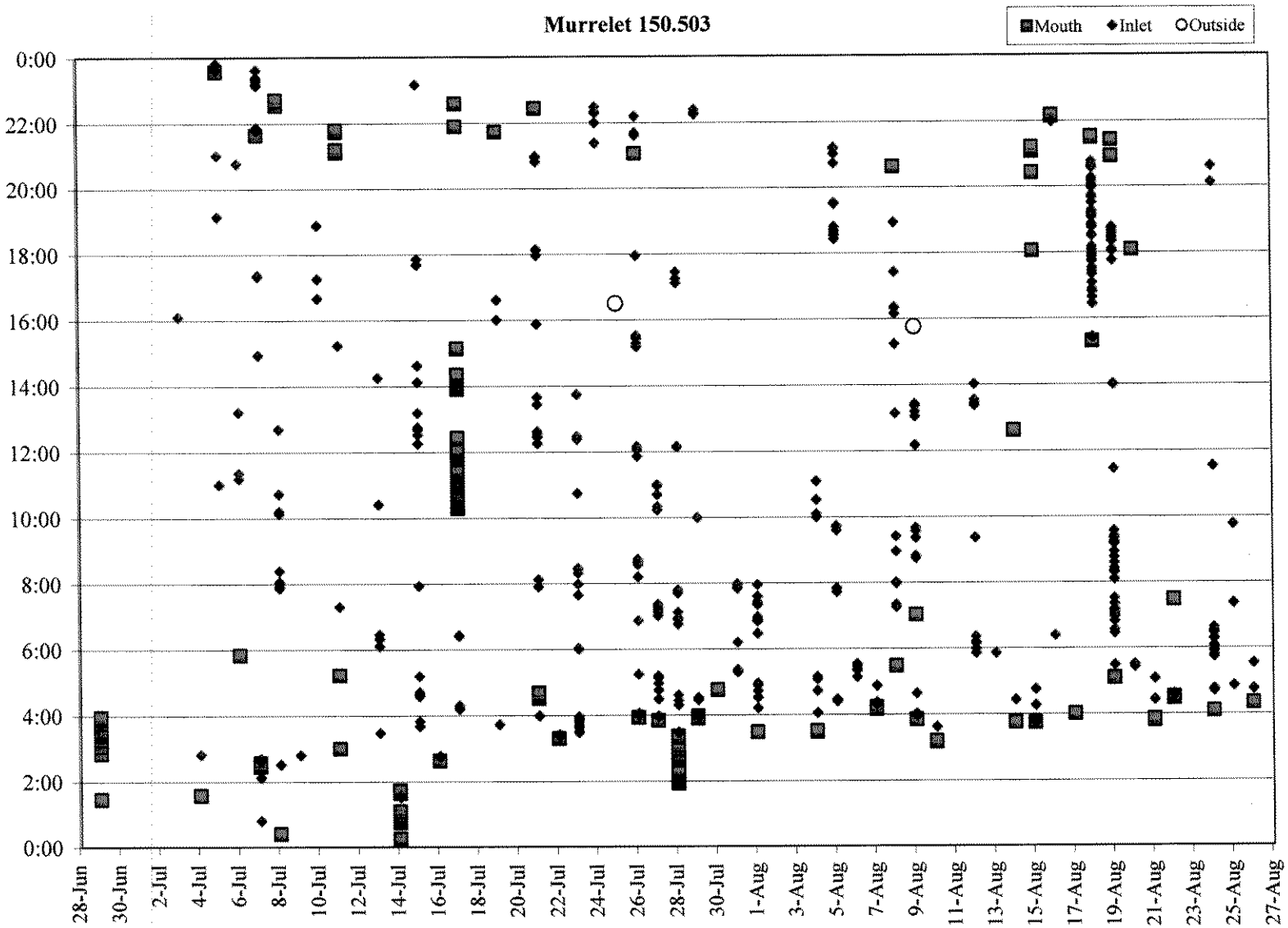
APPENDIX C



Appendix 1.7. Tracking history for Marbled Murrelet 150.444. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

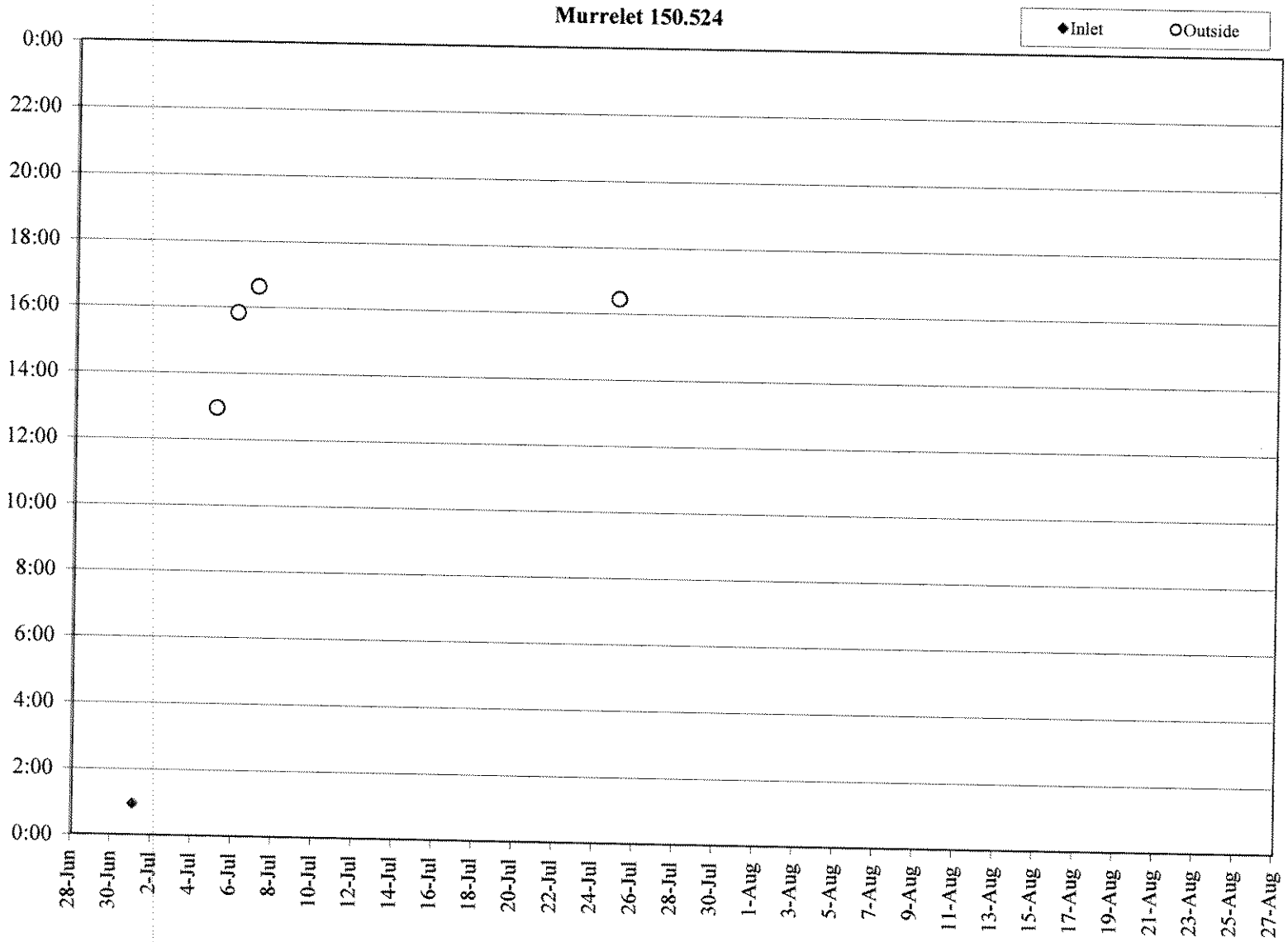


Appendix 1.8. Tracking history for Marbled Murrelet 150.464. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.



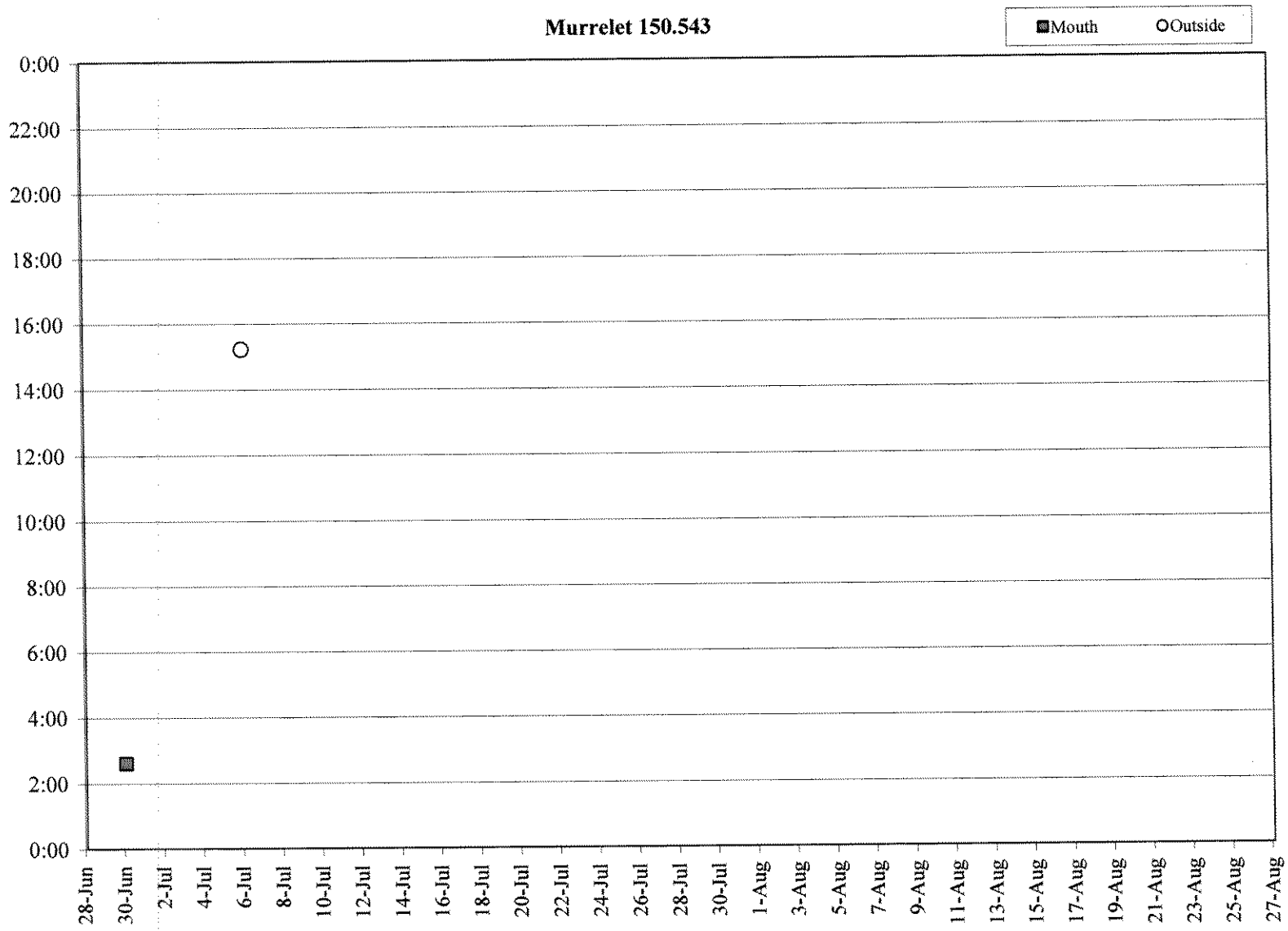
Appendix 1.9. Tracking history for Marbled Murrelet 150.503. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



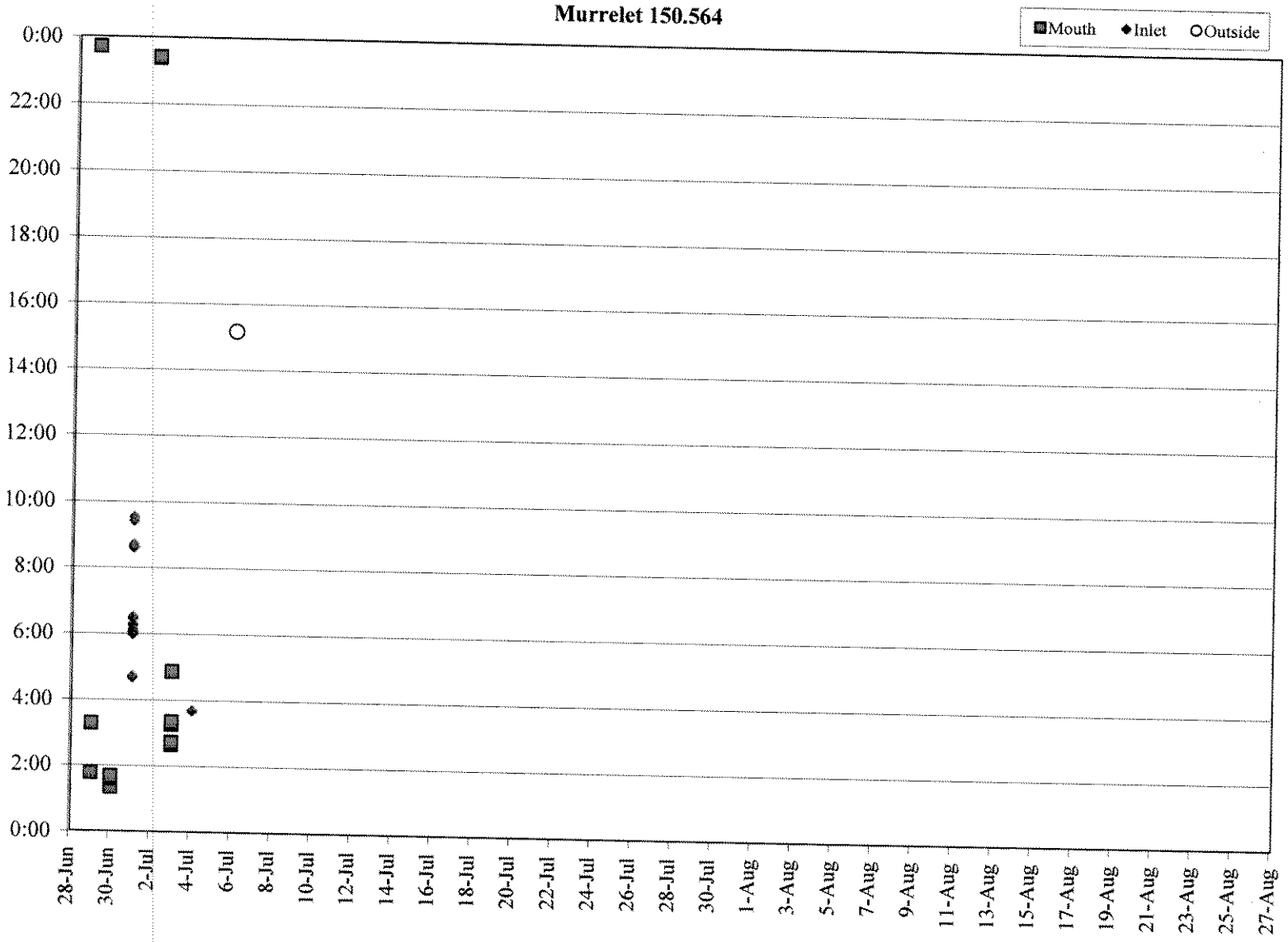
Appendix 1.10. Tracking history for Marbled Murrelet 150.524. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



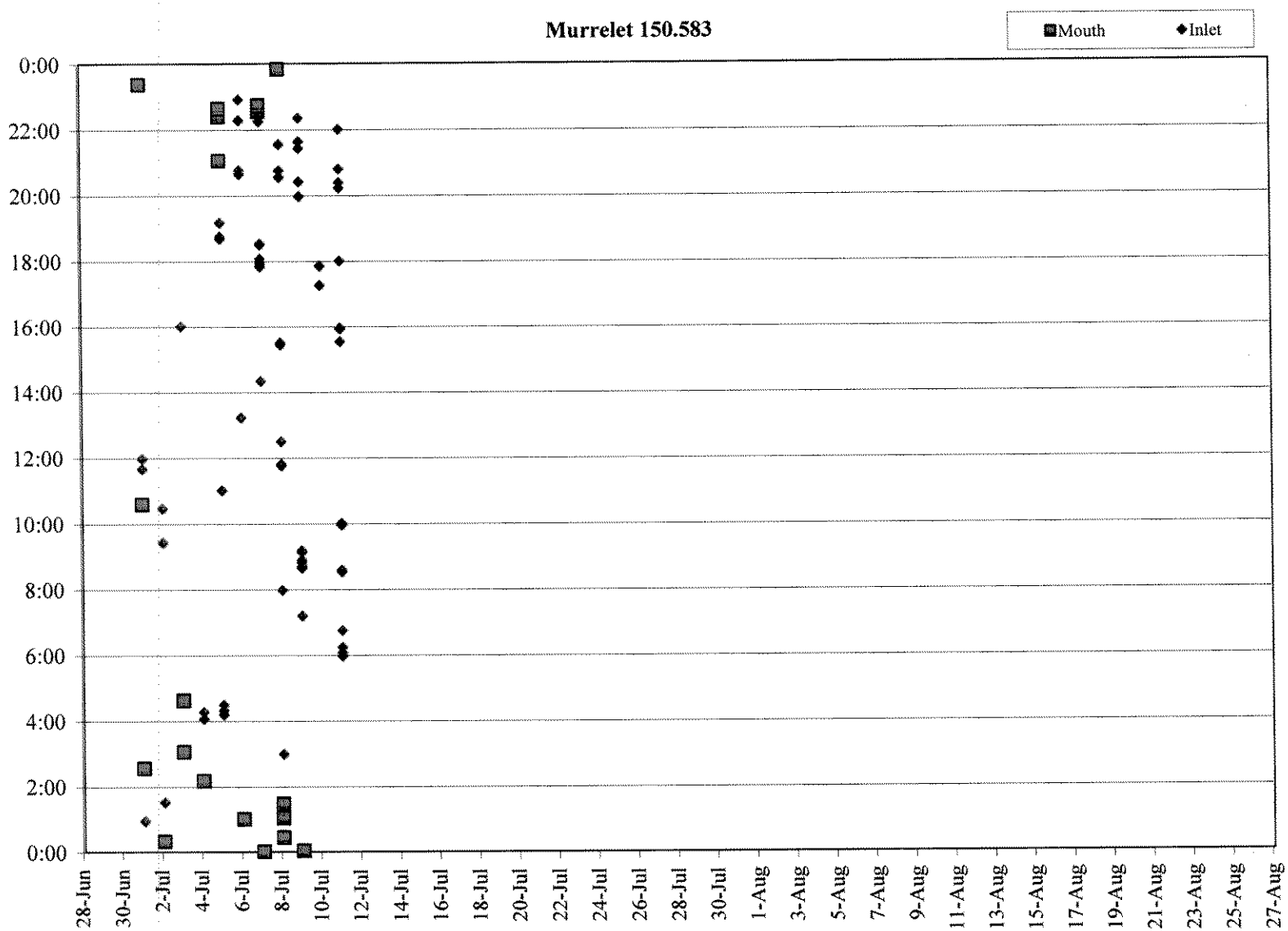
Appendix 1.11. Tracking history for Marbled Murrelet 150.543. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



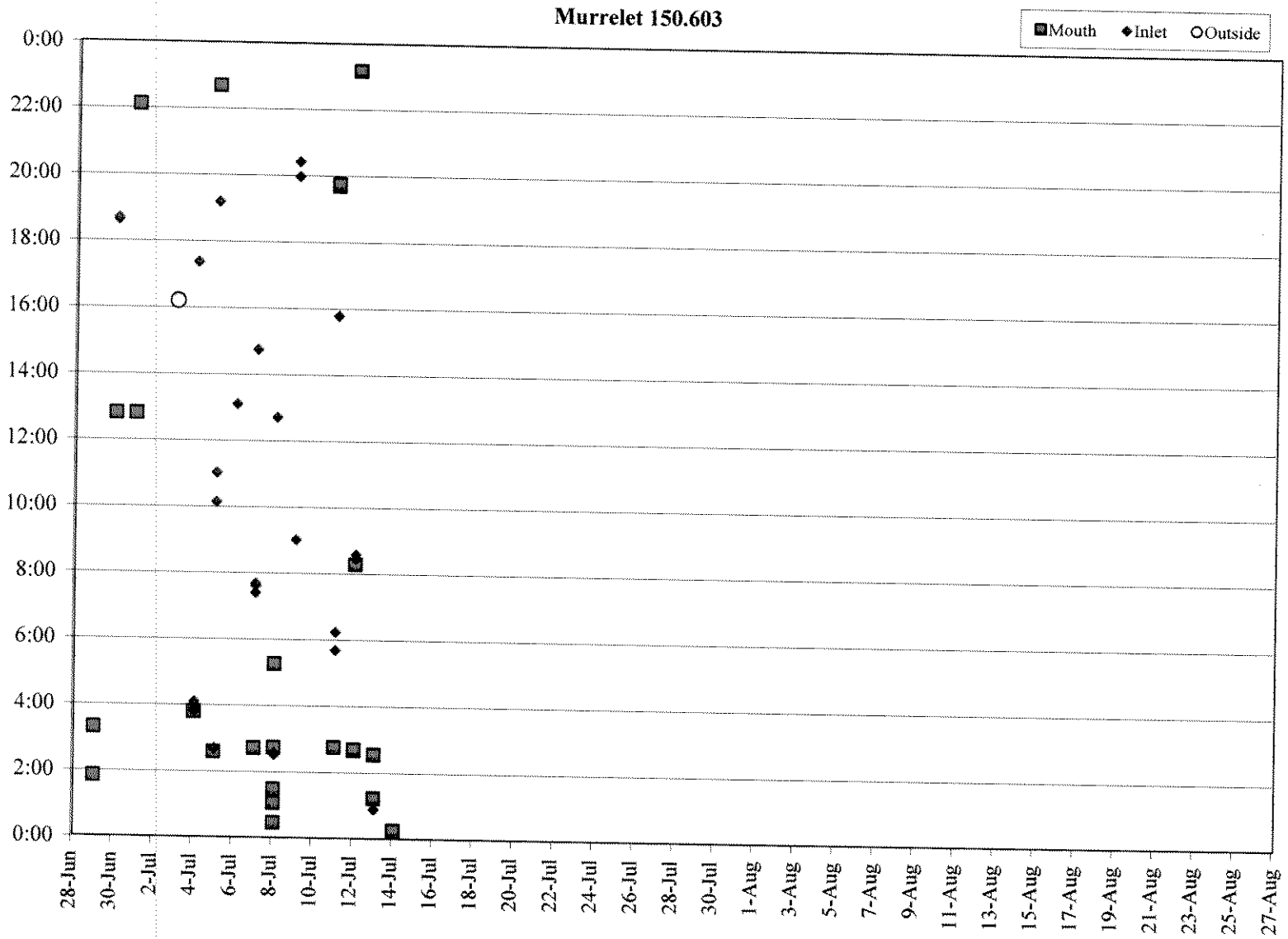
Appendix 1.12. Tracking history for Marbled Murrelet 150.564. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

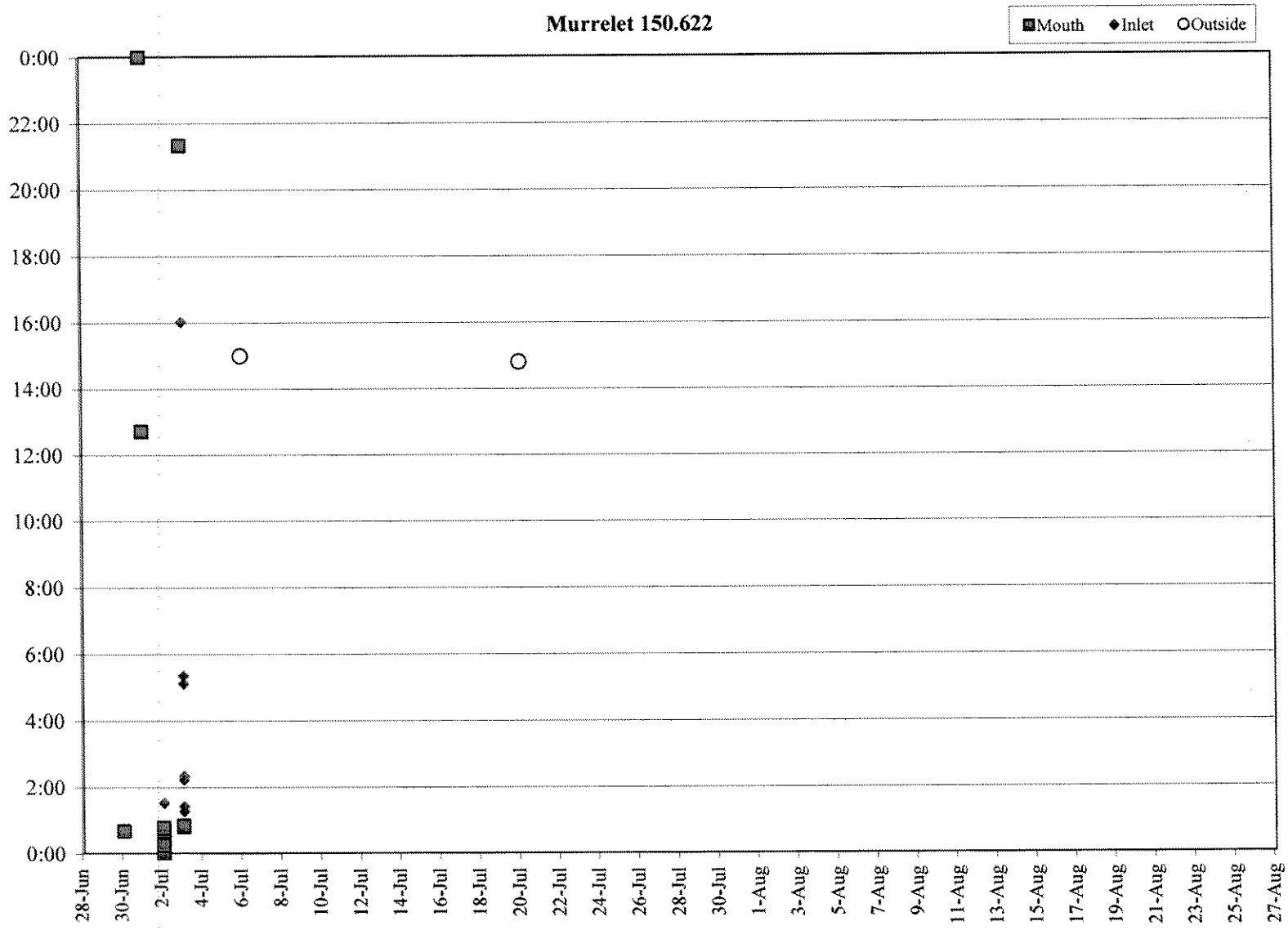


Appendix 1.13. Tracking history for Marbled Murrelet 150.583. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

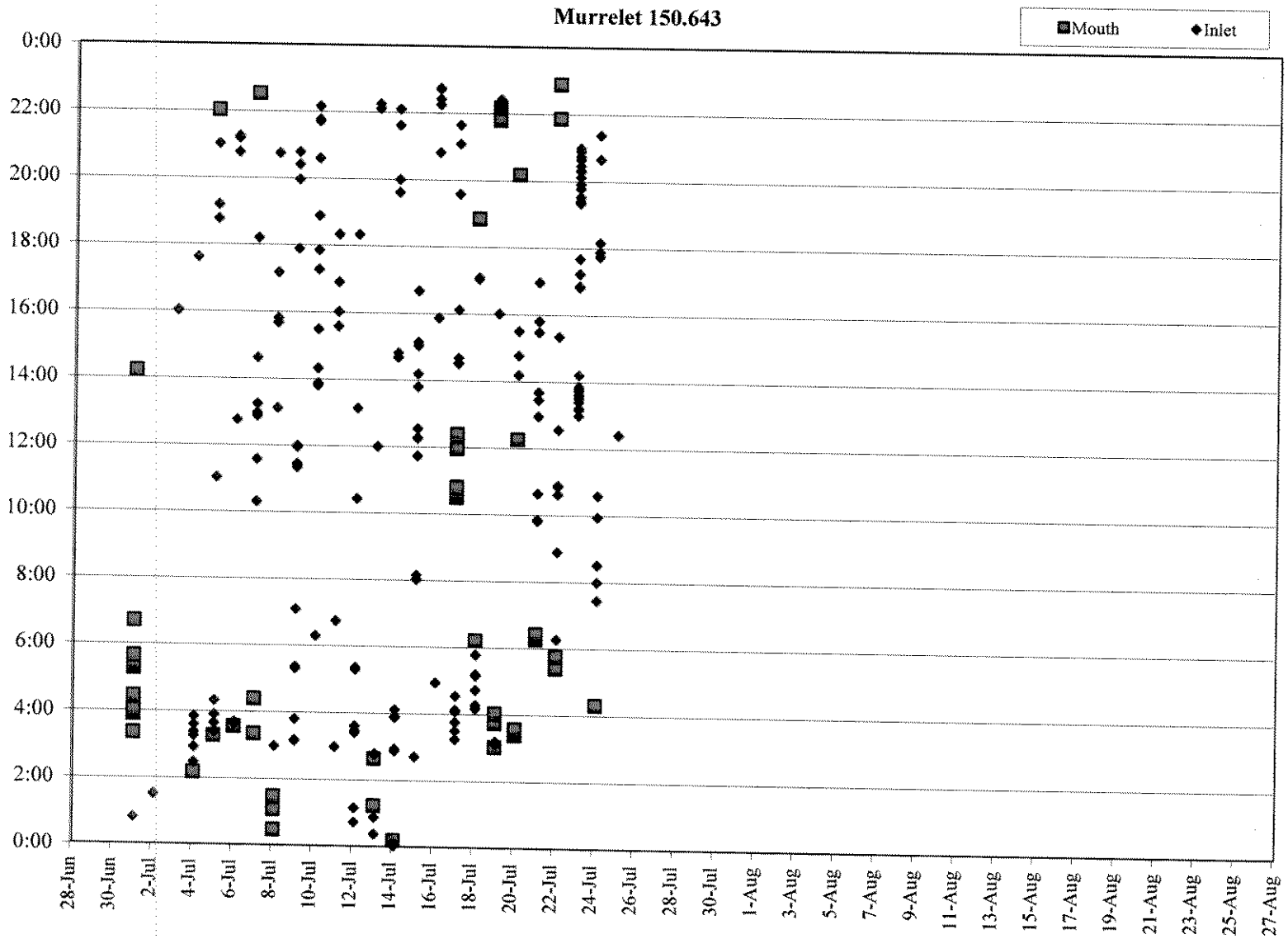
APPENDIX C



Appendix 1.14. Tracking history for Marbled Murrelet 150.603. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

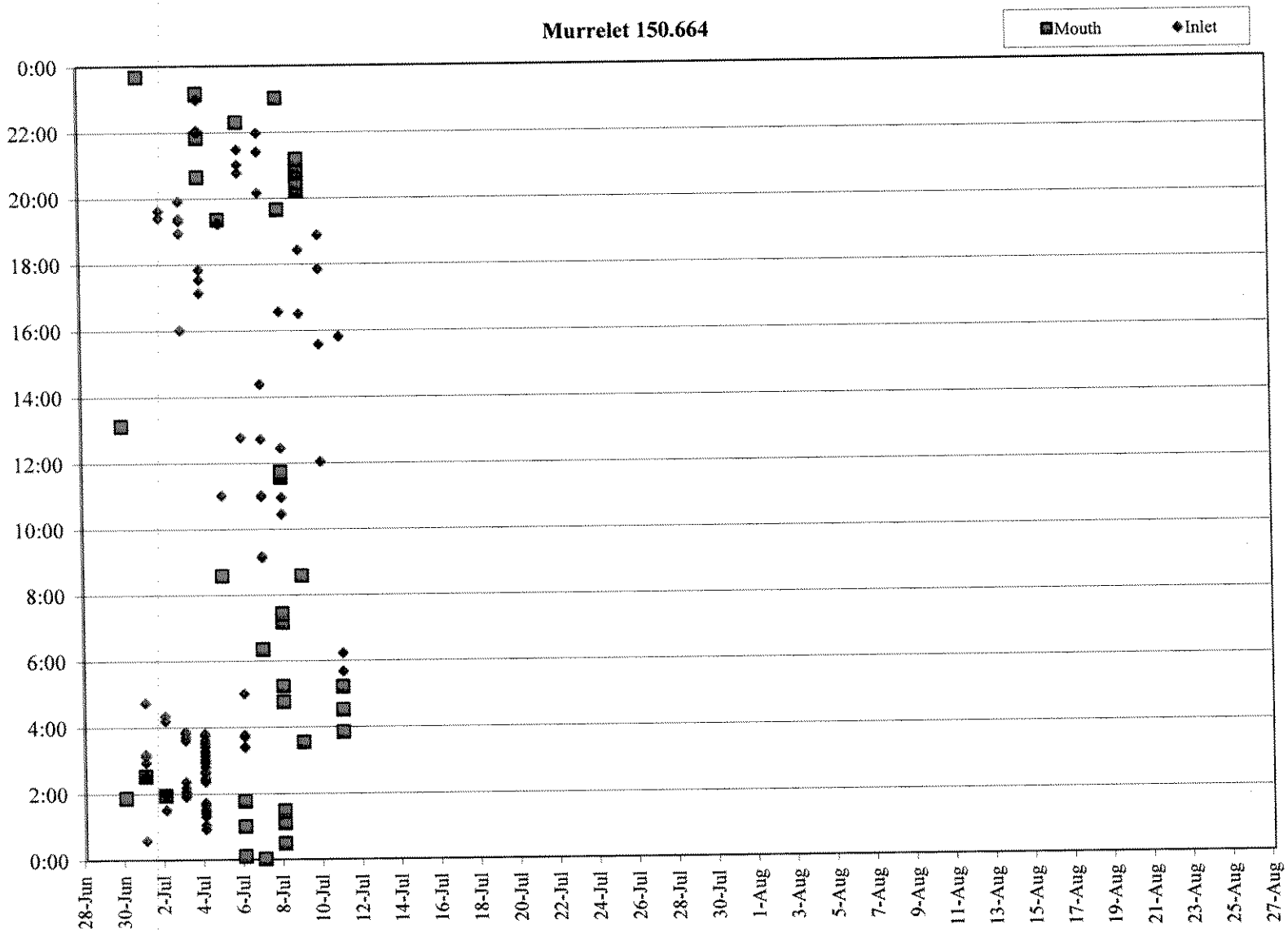


Appendix 1.15. Tracking history for Marbled Murrelet 150.622. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.



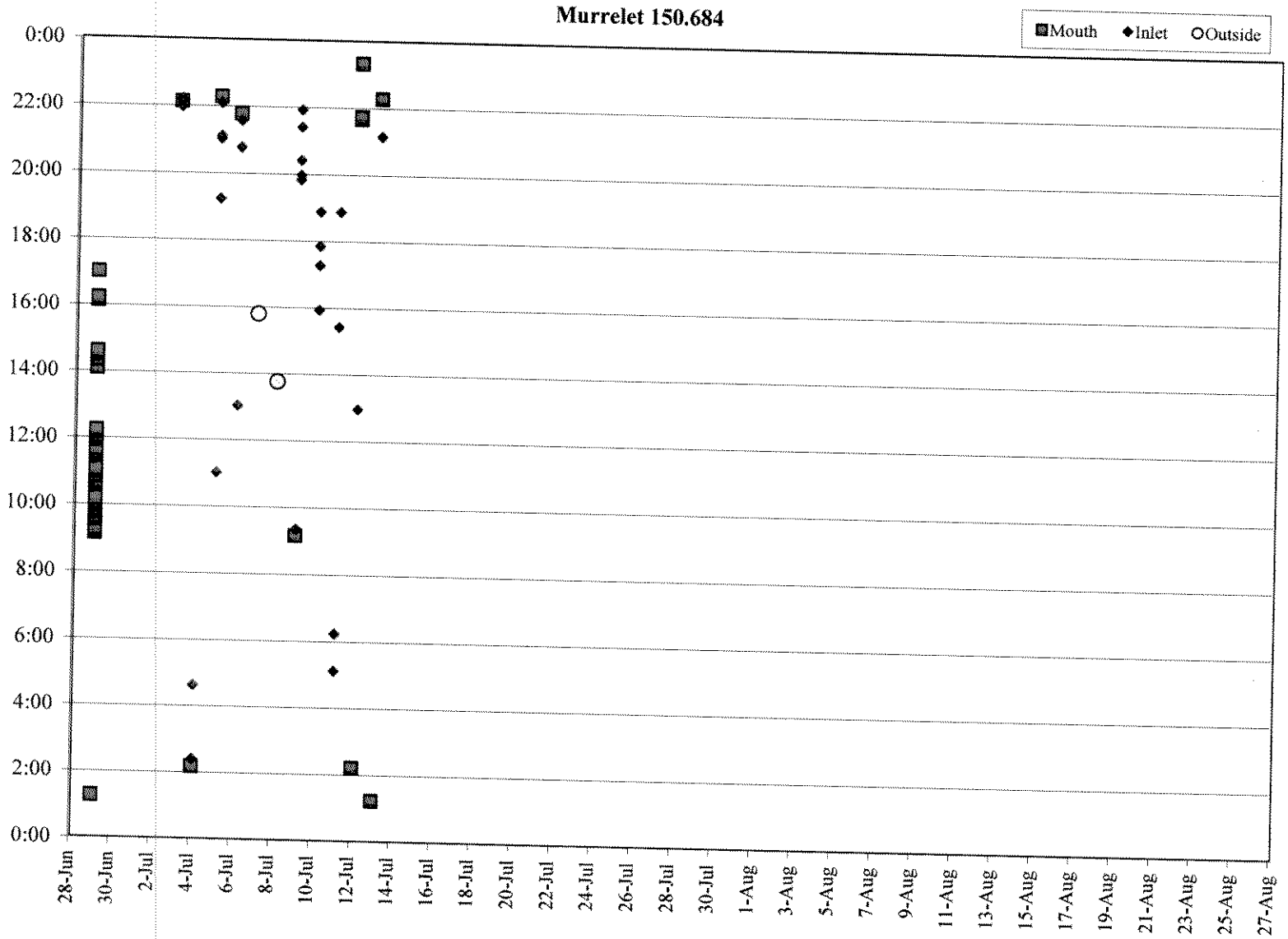
Appendix 1.16. Tracking history for Marbled Murrelet 150.643. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

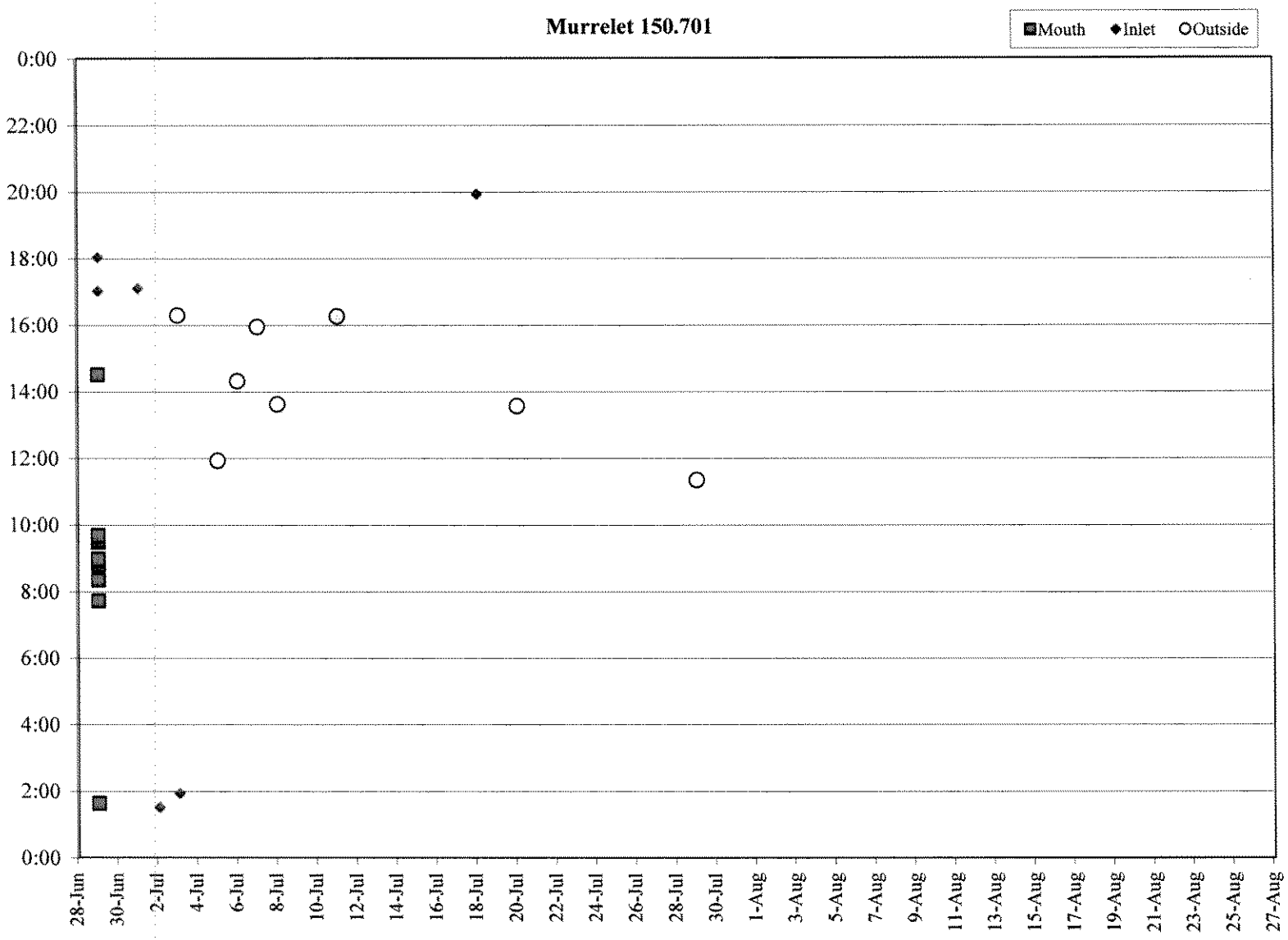


Appendix 1.17. Tracking history for Marbled Murrelet 150.664. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

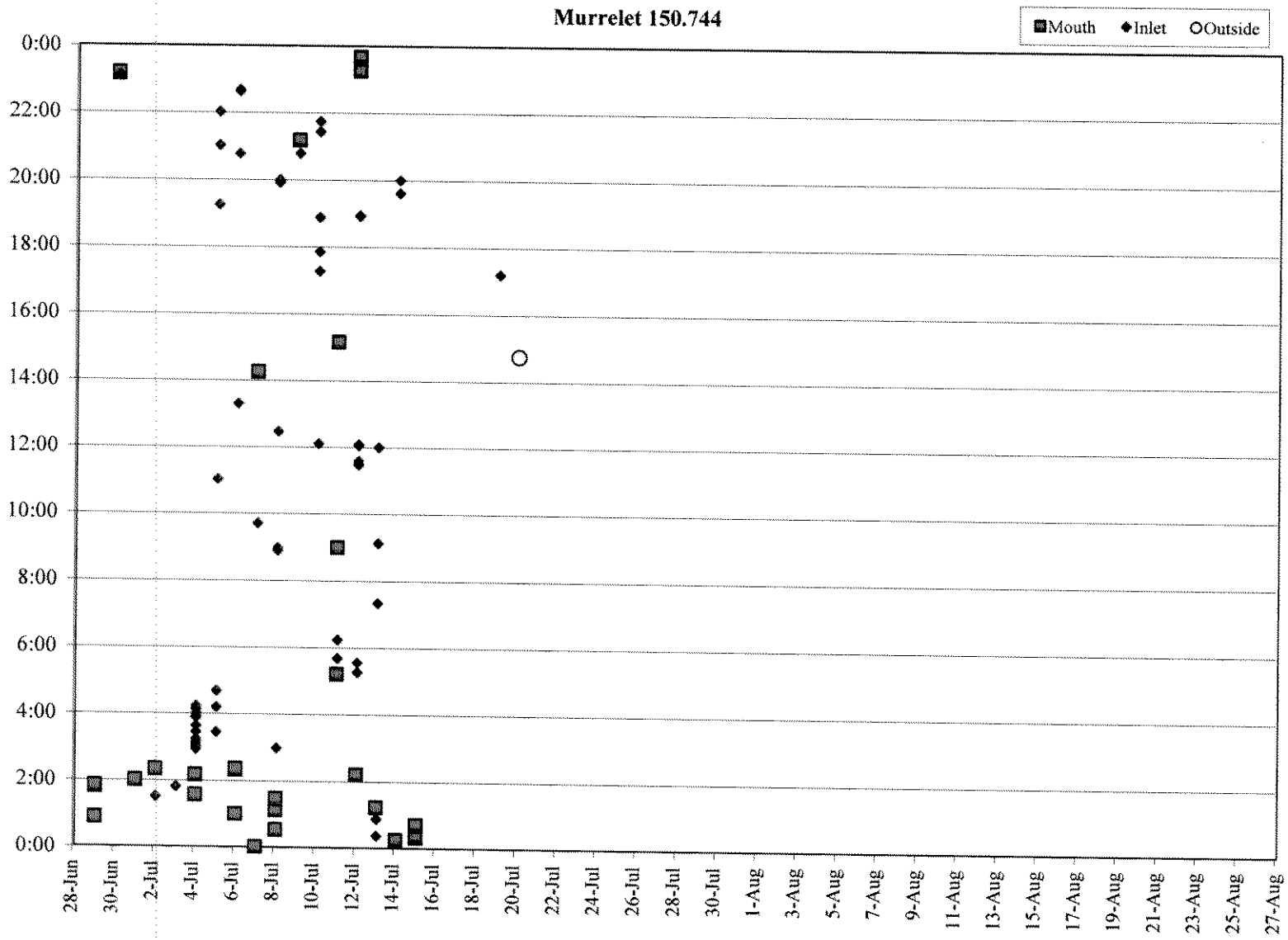


Appendix 1.18. Tracking history for Marbled Murrelet 150.684. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.



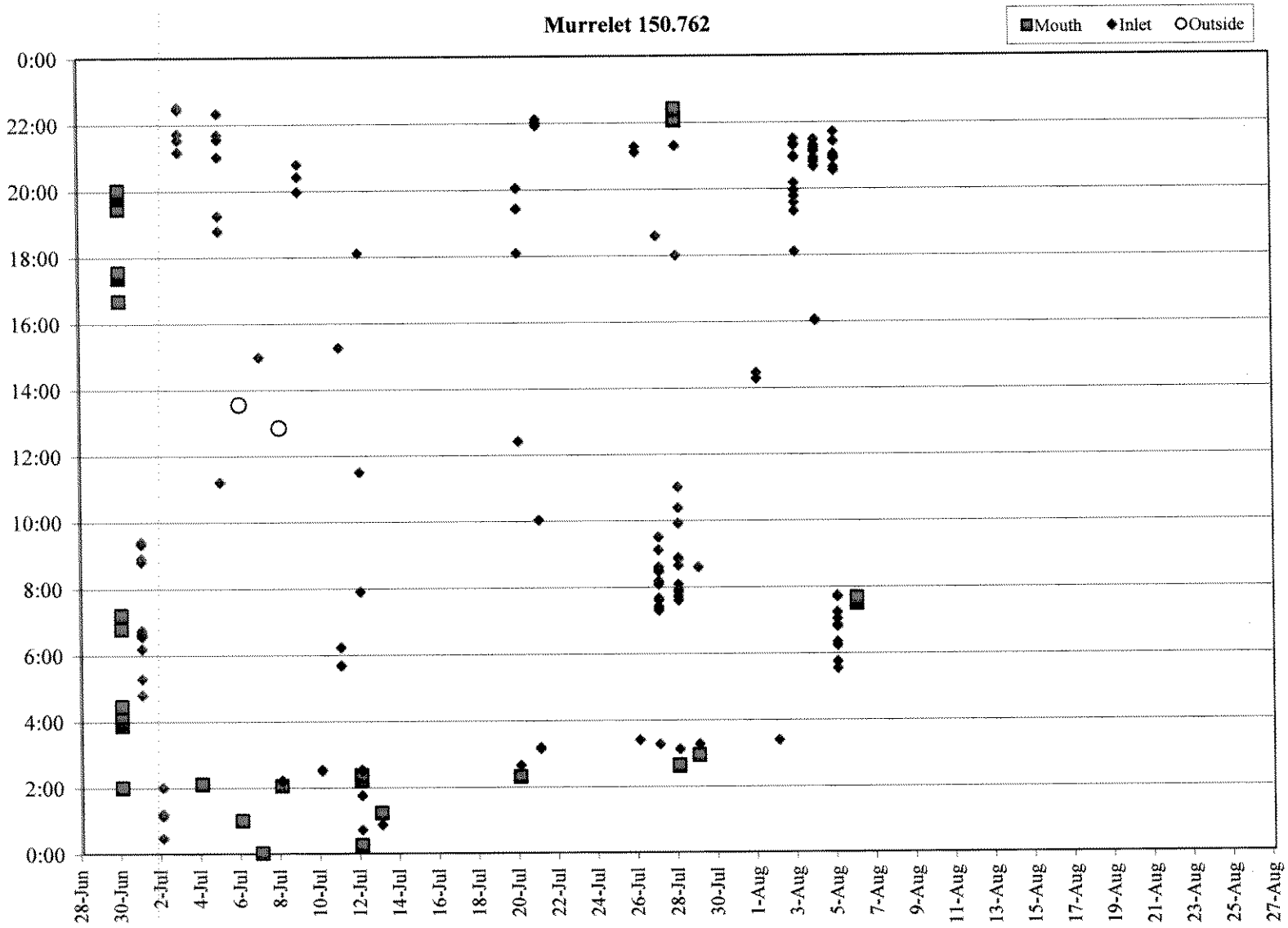
Appendix 1.19. Tracking history for Marbled Murrelet 150.701. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



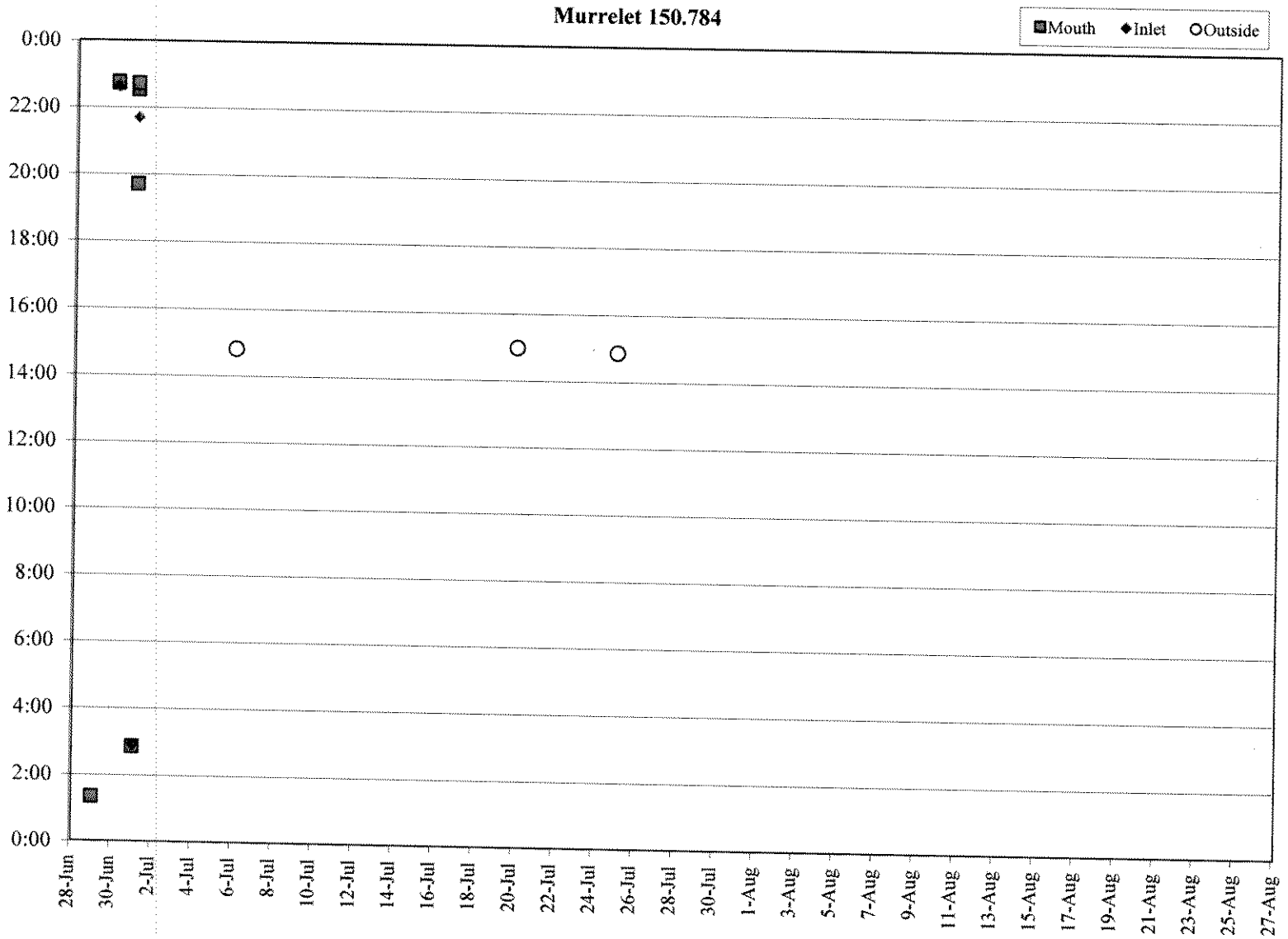
Appendix 1.20. Tracking history for Marbled Murrelet 150.744. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

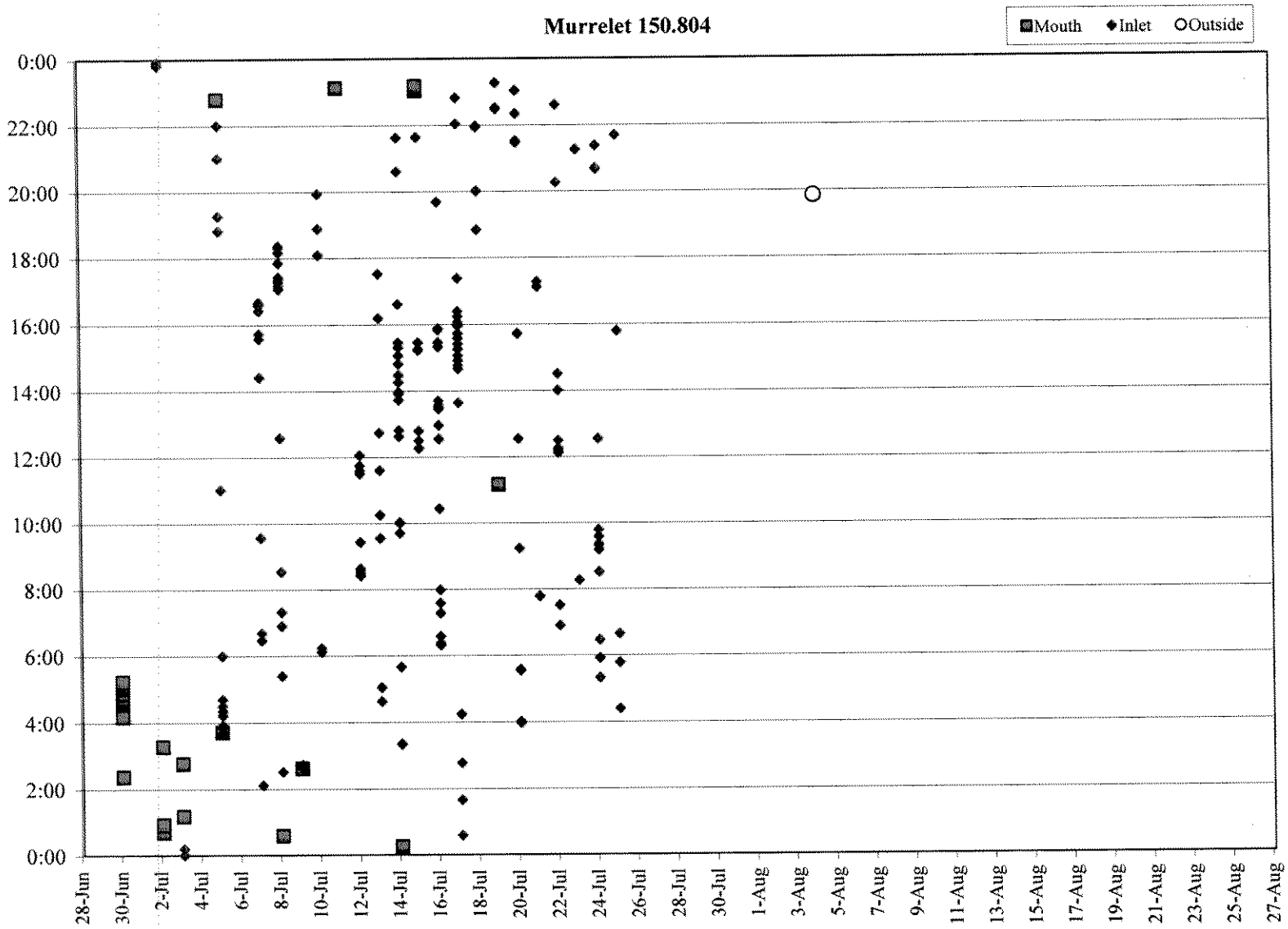


Appendix 1.21. Tracking history for Marbled Murrelet 150.762. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

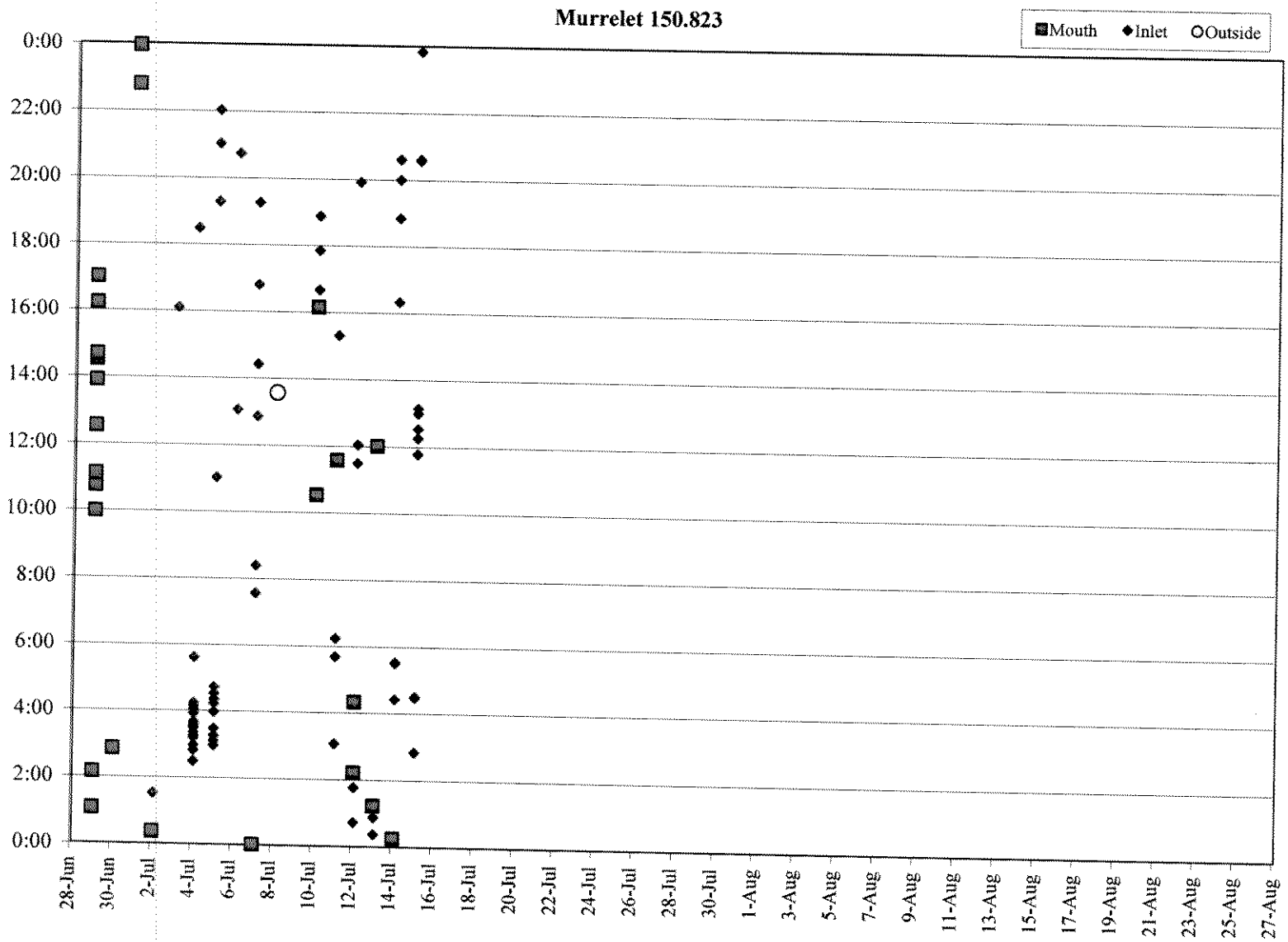
APPENDIX C



Appendix 1.22. Tracking history for Marbled Murrelet 150.784. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

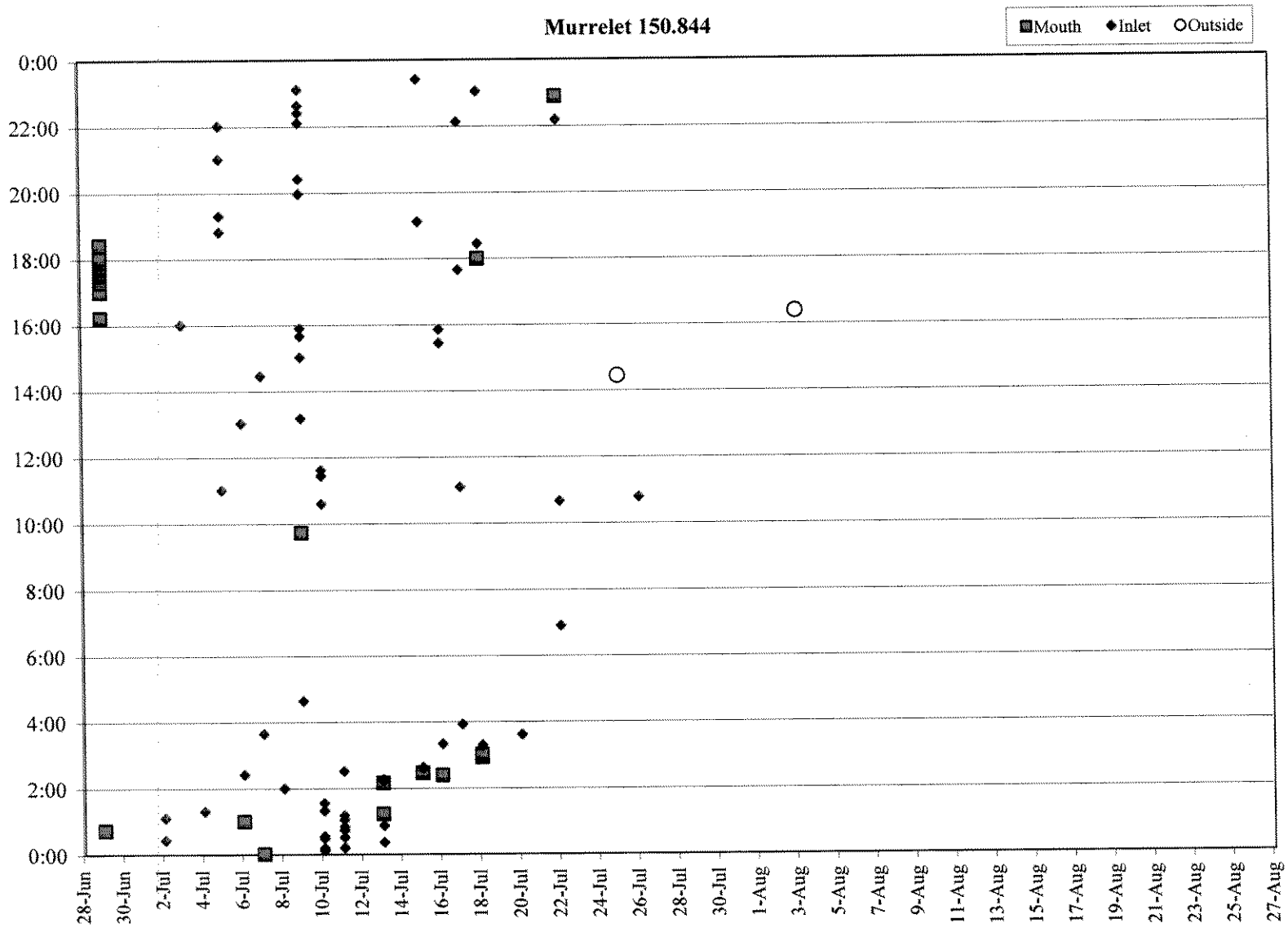


Appendix 1.23. Tracking history for Marbled Murrelet 150.804. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

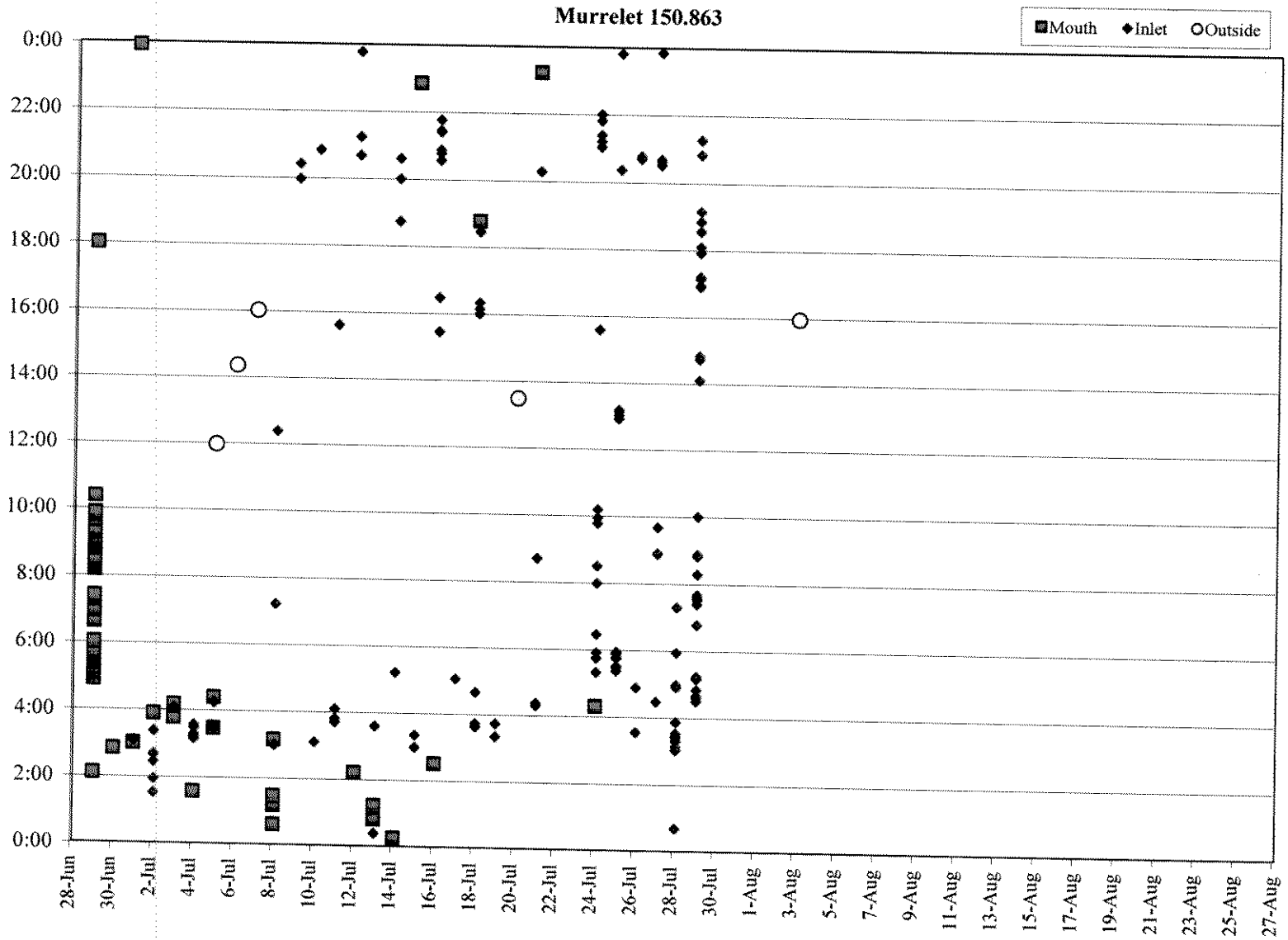


Appendix 1.24. Tracking history for Marbled Murrelet 150.823. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C

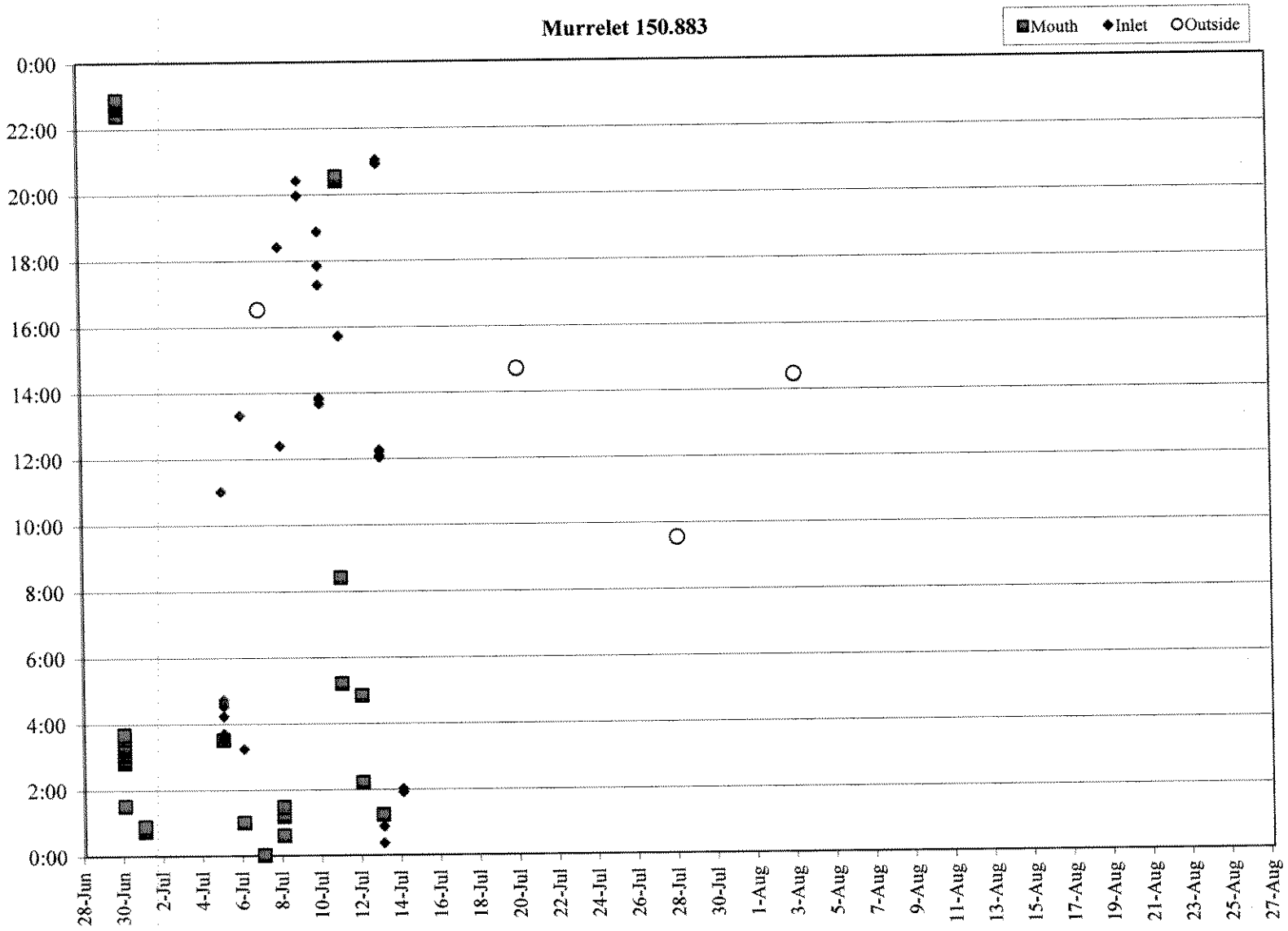


Appendix 1.25. Tracking history for Marbled Murrelet 150.844. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

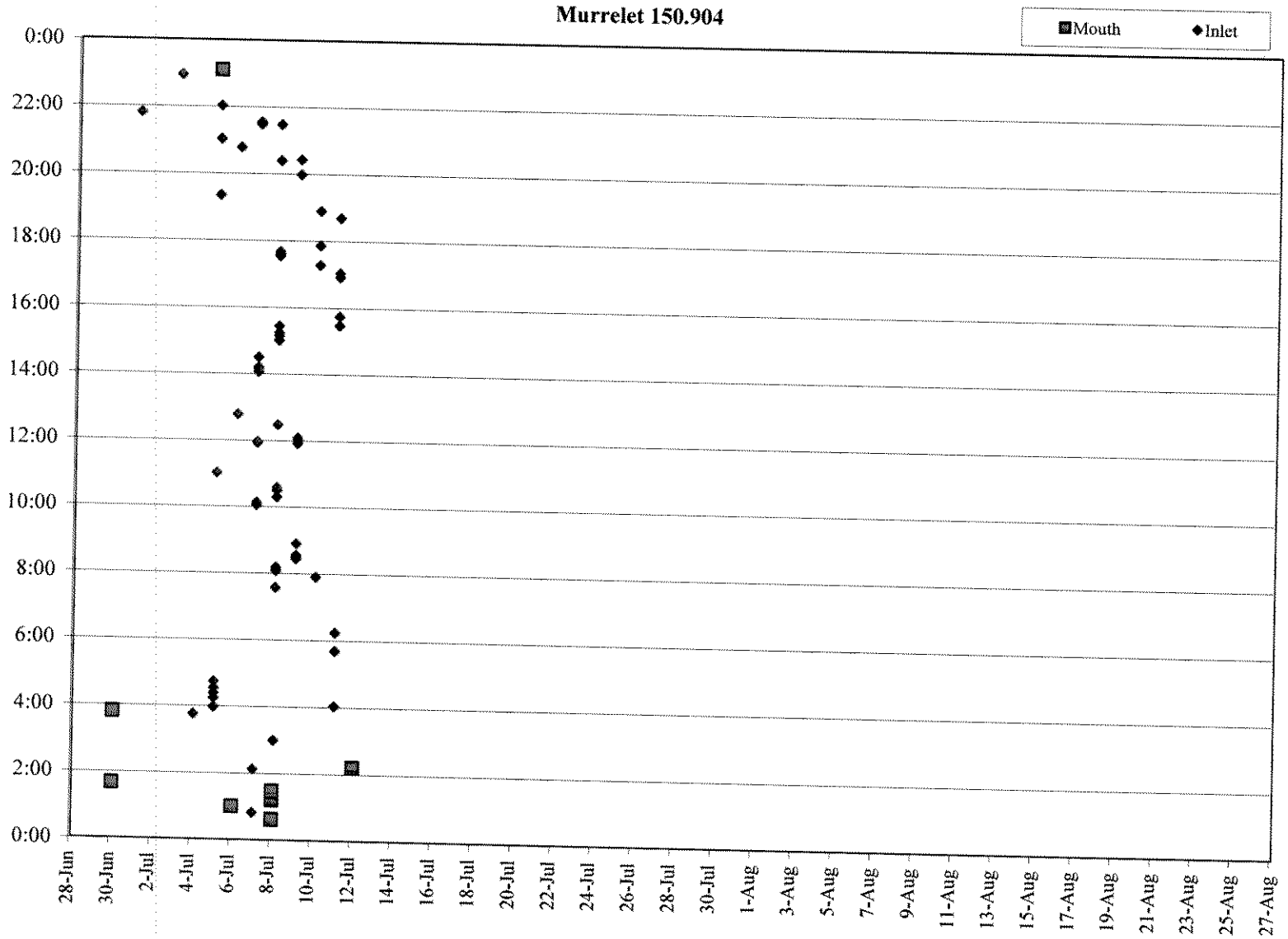


Appendix 1.26. Tracking history for Marbled Murrelet 150.863. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

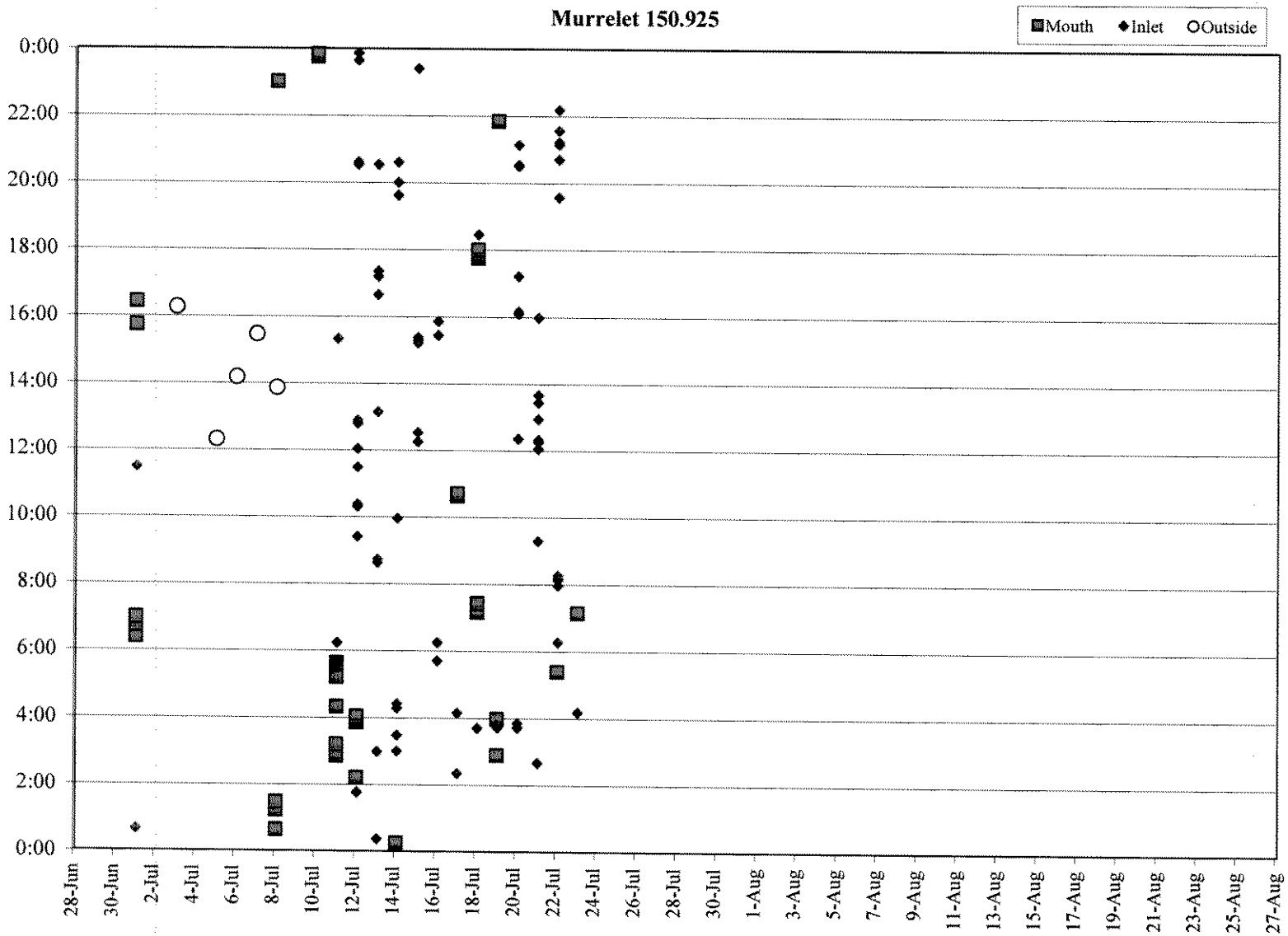
APPENDIX C



Appendix 1.27. Tracking history for Marbled Murrelet 150.883. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

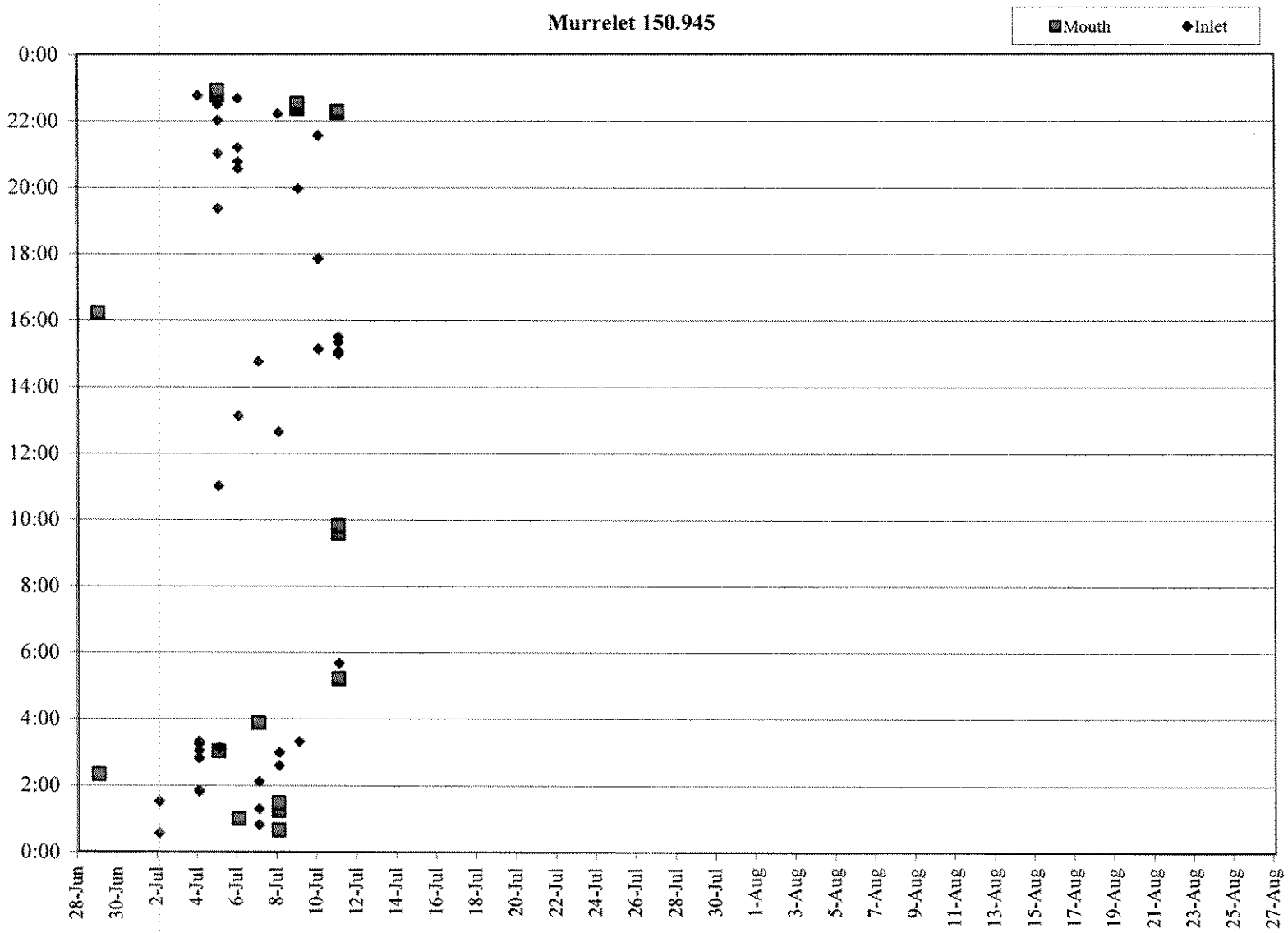


Appendix 1.28. Tracking history for Marbled Murrelet 150.904. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.



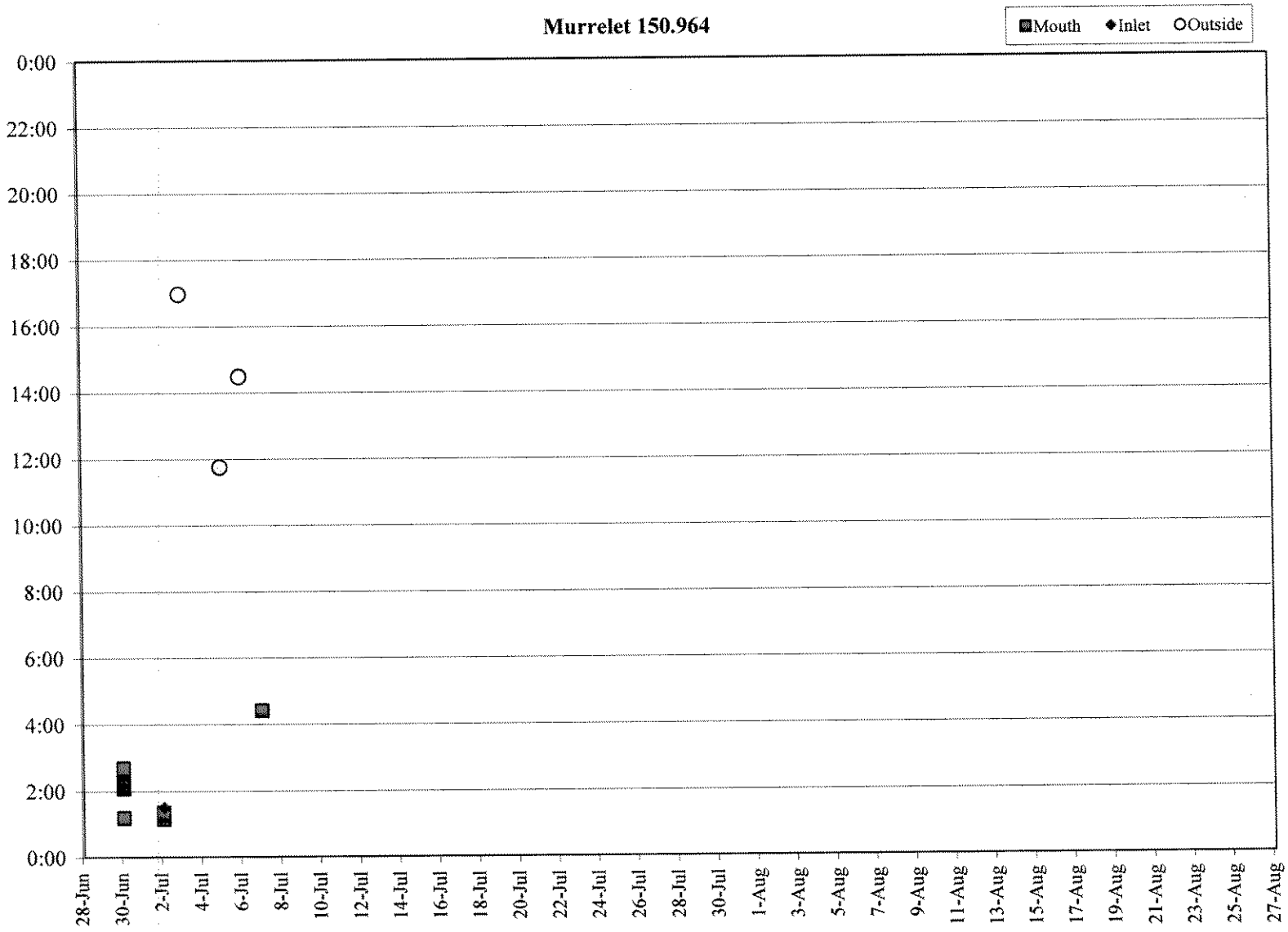
Appendix 1.29. Tracking history for Marbled Murrelet 150.925. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



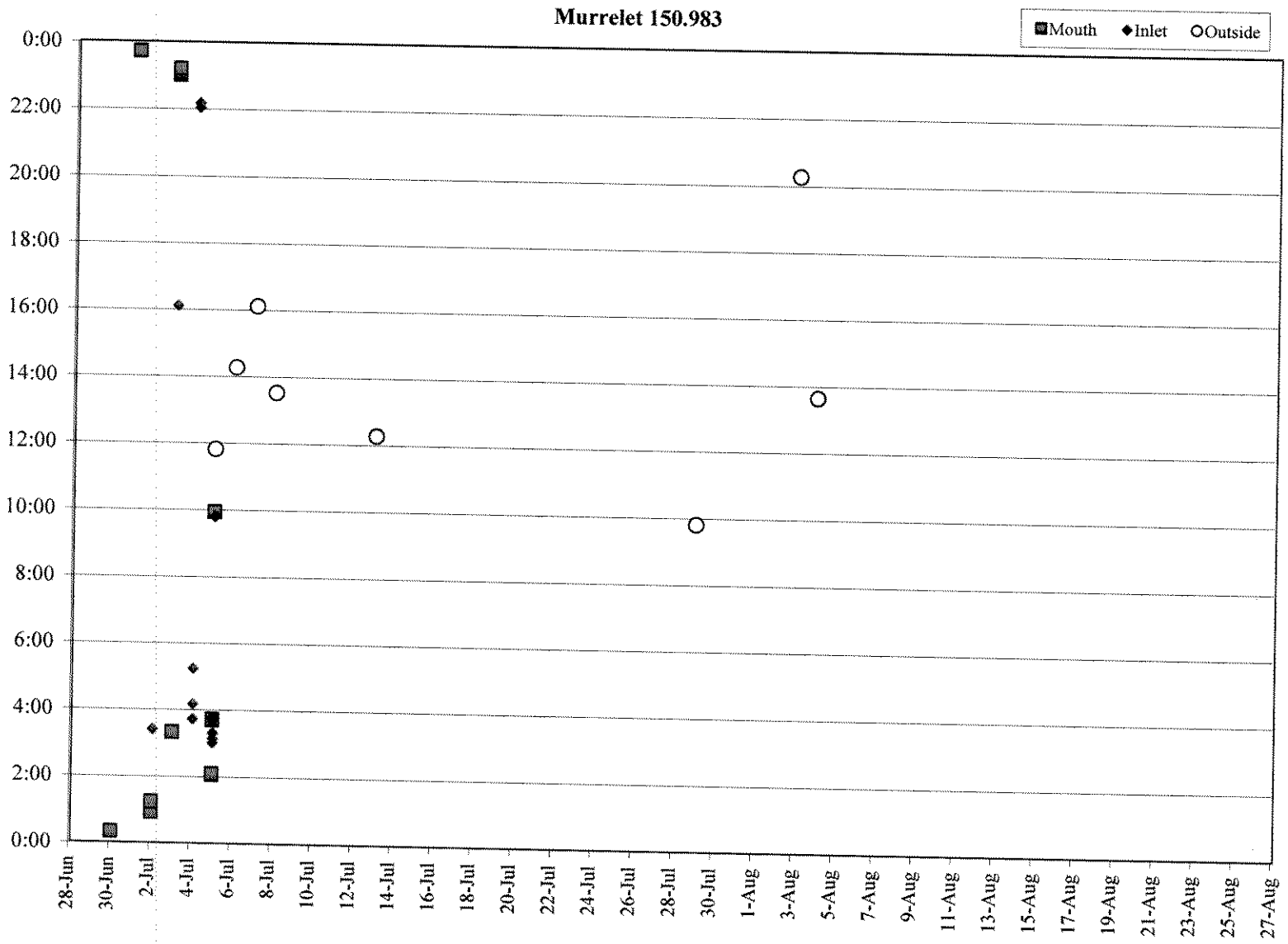
Appendix 1.30. Tracking history for Marbled Murrelet 150.945. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



Appendix 1.31. Tracking history for Marbled Murrelet 150.964. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

APPENDIX C



Appendix 1.32. Tracking history for Marbled Murrelet 150.983. Data include signals detected during aerial surveys, boat surveys and data logger monitoring within (inlet), at the mouth of (mouth) or outside Port Snettisham.

Health Assessment of Marbled Murrelets in Port Snettisham, SE Alaska

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Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*, hereafter MAMU) is a Pacific Northwest seabird in the Alcid family. Its geographic range extends from the Aleutian Islands to central California (Nelson 1997). Southeast Alaska is the geographic center of the MAMU population, with large populations also located in Prince William Sound, the Kodiak Island archipelago, and coastal British Columbia (Piatt *et al.* 2006).

MAMU populations have declined significantly since the early 1980s (Ralph *et al.* 1995, McShane *et al.* 2004, Piatt *et al.* 2006). From 2004-2006, the total North American population was estimated to be 300,000-400,000 individuals, with roughly 80% of the population occurring in Alaska (McShane *et al.* 2004, Piatt *et al.* 2006). Over the past 25 years, it is thought the Alaskan population has declined by as much as 70% (Piatt *et al.* 2006). Factors in their decline include the loss of old-growth nesting habitat (Ralph *et al.* 1995; Nelson 1997), fishing-net mortality (Carter *et al.* 1995), the threat of oil spills and other environmental pollutants (Carter and Kuletz 1995), climate change affecting prey abundance and distribution (Agler *et al.* 1999), short-term environmental phenomena such as El Niño (Burger 2000), native and introduced predators, and at-sea disturbances (McShane *et al.* 2004, Piatt *et al.* 2006).

Building a better understanding of the biology and ecology of threatened seabird populations such as those of MAMU is important for conservation and management. Additionally, seabirds can serve as indicators of ecosystem status and change. They are highly visible, easy to enumerate (Sydeman *et al.* 2006) and relatively easy to study. As top predators, seabirds accumulate nutrients and toxins from their prey and the environment in their blood and tissues. Their health is therefore directly linked to the health of the ecosystem that they inhabit.

Health assessments of seabirds provide baseline health information, insight into stresses on populations, and can act as measures of overall environmental health. In veterinary and human medicine, hematology and clinical pathology tests are utilized to obtain a snapshot of health. Hematological parameters such as total white blood cell and differential cell counts reflect immunological status (Campbell 1995), while biochemical parameters reflect the status of internal organs, electrolytes, proteins, and nutritional and metabolic parameters. Blood analyses can identify organ systems affected by infectious disease, toxins, biotoxins, metabolic diseases or nutritional deficiencies (Newman *et al.* 1997). Additionally, disease screening has become an important index in health assessments, including Avian Influenza and Newcastle Disease status.

Almost half of the United States' total surface waters are located in Alaska, and although less than 0.1% of Alaska's water resources have been identified as impaired, there remain several threats (Anonymous 2008). The relationship between water quality and ecosystem health is also of growing concern for seabirds as marine habitats continue to see heavy commercial and industrial uses. Oil pollution remains a constant threat in Alaska (Carter and Kuletz 1995; McShane *et al.* 2004), and oil spills in the past have been responsible for the death of many seabirds. As tourism in Southeast Alaska grows, there is growing concern over ammonia, copper, nickel, and zinc pollution from cruise ship discharges. Efforts to improve discharge quality have been made with the Cruise Ship Initiative passed in 2006 (Kent and Koch 2008). Mining also poses another threat to water quality because discharges from mining include sediments that increase turbidity and mercury wastes (Anonymous 2008).

Not only do pollutants directly affect the health of seabirds, but indirectly through the bioaccumulation of contaminants ingested by their prey. The prey base for MAMU across their range includes invertebrates such as euphausids, mysids and amphipods, and forage fishes such as sand lance (*Ammodytes hexapterus*), herring (*Clupea Pallasii*), perch (Embiotocidae), osmerids (Osmeridae), and anchovy (Burkett 1995). If environmental conditions and food resources are compromised, the health of MAMU and other organisms in Southeast Alaskan ecosystems could be affected. Detrimental effects would, in turn, be indicated by changes in blood health indices (Newman *et al.* 2007).

The health of murrelets can be more carefully examined by exploring the differences in hematological and biochemical parameters between male and female birds. Both male and female MAMU take part in the incubation and chick-rearing process, with the relative investment made by each gender reflecting trade-offs, energy constraints, and life history strategy (Roff 1992). For females, egg production comes at a high energy cost, with eggs making up about 20% of their body mass (Nelson 1997). Researchers in British Columbia found that males provisioned chicks more often than females, particularly in the second half of chick-rearing (Bradley *et al.* 2002). Large investments of energy may affect health by increasing stress on the body and changing physiological conditions. Because males and females invest varying amounts of energy at different times in the breeding season, this may be reflected in differences in health parameters.

This study examines MAMU health in Port Snettisham, Southeast Alaska, from 2005 to 2007. We collected blood, feather, and cloacal swab samples concurrent with fitting birds with VHF radio transmitters to track movements and determine breeding status. The baseline health data established for the MAMU population in Port Snettisham, AK will be a valuable tool for future monitoring efforts and allow for health comparisons of murrelets across their range.

We compared biochemical parameters between MAMU from Southeast Alaska and California in order to construct a more detailed picture on whether health parameters vary geographically. As populations decline, another threat becomes increased inbreeding, leading to inbreeding suppression and the loss of genetic variability which may reduce a species' ability to adapt and evolve, therefore making the preservation of genetic diversity important (Piatt *et al.* 2007). A study of four introns and three microsatellite loci revealed significant differentiation in peripheral populations of MAMU in California and the Aleutian Islands, while the center of the population in Alaska showed little differentiation (Friesen *et al.* 2005). Although MAMU populations do not currently seem to be at risk for inbreeding suppression (Piatt *et al.* 2007), these genetically unique populations are of particular conservation concern to preserve genetic diversity. Geographical comparisons of biochemical parameters may reveal differences between central range and peripheral populations and give insight into possible causes for declines in peripheral populations. Such data can form a baseline that can be used to monitor the health of MAMU throughout their range.

Methods

Blood samples were analyzed for hematological parameters and genetic material from red blood cells was used to determine gender. Plasma samples were analyzed for biochemical parameters, and cloacal swab samples from 2007 were analyzed to determine Avian Influenza and Exotic Newcastle Disease status. Biochemical results from Alaska MAMU collected between 2005 - 2007 were compared to biochemical results from California MAMU sampled between 1997 - 2000.

Study Site – Southeast Alaska

MAMU were captured in Southeast Alaska at the mouth of Port Snettisham (hereafter PS) (57°58'N, 133°55'W), 40 km south of Juneau. PS is part of a large system of channels with fjord characteristics. It has a water surface area of approximately 80 km^2 and is surrounded by old-growth forest habitat. The region is strongly influenced by freshwater inputs with two major watersheds, the Speel and the Whiting Rivers, and numerous smaller freshwater inputs. Human use of the area is limited. Boats have traveled up Stephen's Passage, next to PS, for the past century, and increases in tourism have become a concern in the preservation of water quality in the area. Besides this, use is limited to a small amount of seasonal commercial fishing and recreational boat traffic and a salmon hatchery on the Speel River.

Capture and Sampling – Port Snettisham, AK

From 2005 to 2007, blood samples were taken from 101 MAMU in PS (42, 36 and 23 in each year, respectively). Captures were conducted between 28 June - 11 July in 2005, 26 April - 1 May in 2006 and 15-16 May in 2007. MAMU were captured at the mouth of PS between 23:00 h and 4:00 h using the dip-net method (Whitworth *et al.* 1997). MAMU were banded, measured for mass, culmen and tarsus length, and brood patches evaluated (Sealy 1974) prior to radio transmitter attachment. Radio transmitters (Model A1555, ATS, Isanti, MN, USA) were attached to birds using the subcutaneous anchor method (Newman *et al.* 1999). Exposure (30-90 sec) to an inhalation anesthetic, isoflurane, was used to sedate every MAMU in 2005 and every other MAMU in 2006 and 2007 prior to radio transmitter attachment. Following attachments of transmitters, blood samples were collected from the medial metatarsal vein (0.3–0.6 cc/100 g bird mass) using a 25 G needle and 3 mL syringe. Blood was immediately placed in lithium heparin gel separator tubes (Microtainer, Becton-Dickinson, Franklin Lakes, NJ, USA) and stored at approximately 3 °C. Two blood smears were prepared upon returning to the field camp and air-dried. Plasma was separated by centrifugation between 4–8 h after collection. Cloacal swab samples were collected from MAMU in 2007 and were tested for Avian Influenza Virus and Newcastle Disease Virus. MAMU were released in the proximity (10-200 m) of the capture locations.

Comparison Study Site – Año Nuevo Bay, Central California

Año Nuevo Bay (hereafter ANB), California is on the central coast (37°05'N, 122°15'W), near Santa Cruz. The MAMU population in ANB represents the southern extent of their breeding range (Ralph *et al.* 1995), with a sandy coastline and rocky outcrops, and old-growth forests located inland (Henkel *et al.* 2004). ANB was classified as a State Marine Conservation Area (SMCA) by the California Department of Fish and Game. The only marine organism permitted to be taken commercially from this area is giant kelp (*Macrocystis pyrifera*) (CADFG 2007). Although California laws regarding oil spill response have improved since the early 1990s, oil pollution remains a threat to wildlife living in ANB (Mazet *et al.* 2002).

Capture and Sampling – Año Nuevo Bay, CA

In ANB, CA, sampling of MAMU occurred in either April or May from 1997 to 2000. Overall, 95 birds were sampled: 43 in 1997, 19 in 1998, 9 in 1999, and 24 in 2000. Capture, handling and sampling techniques were similar to those used in PS. However, no cloacal swab samples were taken.

Hematological Analysis

Blood samples from 2005 (n = 42), 2006 (n = 36), and 2007 (n = 23) were analyzed for white blood cell counts (WBC; indicator of immune competence) (Zinkl 1986) within 48 h of blood collection. Blood smears were stained with Dif Quik™ (American Scientific Products, McGraw Park, IL, USA) and examined at 100× using a light microscope. One hundred WBC's were counted and categorized as eosinophils, heterophils, lymphocytes, monocytes or basophils to get the percentage of each cell type. An Eosinophil Unopette Determination kit Test 5877 (Becton-Dickinson and Co., Franklin Lakes, NJ, USA) was used to perform WBC count. Based on the differential WBC counts, the total WBC was calculated (Campbell, 1995). In California, total WBC was calculated using the modified Natt-herrick technique (Zinkl 1986).

Gender Determination

For both Alaska and California, a small sample (0.05mL) of blood from each MAMU was spotted on a ZooMark DNA collection system card or sent in a cryovial to determine bird gender. Sex was determined using the polymerase chain reaction (PCR) technique to visualize pieces of DNA from the sex chromosomes of each MAMU (Zoogen Inc., Davis, CA, USA).

Biochemical analysis

Lithium heparin gel separator tubes were centrifuged and plasma was transferred to cryovials and frozen at – 80 °C. For MAMU from Alaska, frozen plasma samples were sent to the Division of Comparative Pathology at the University of Miami, Miller School of Medicine for biochemical analysis using an Ortho (Kodak Ektahem) 700XR. For MAMU from California, frozen plasma samples were sent to the University of California, Davis, School of Veterinary Medicine. Activity levels of alanine amino transferase (ALT) and aspartate amino transferase (AST) were measured as indicators of liver function; creatine phosphokinase (CPK) and lactate dehydrogenase (LDH) were measured as indicators of muscle function; calcium (CAL) and phosphorus (PHOS) were measured as indicators of electrolyte activity and acid/base balance; glucose (GLU) was measured as an indicator of nutrition and metabolism; total protein (TP) was measured as an indicator of immuncompetence; and uric acid (URIC) was measured as an indicator of kidney function.

Disease analysis

Cloacal swab samples taken from MAMU in 2007 (n = 40) were sent to the Alaska State Veterinarian in Anchorage, AK, to be analyzed for Avian Influenza Virus (AIV) and Virulent Newcastle Disease Virus (vNDV). Samples were analyzed according to the standard operating procedures dictated by the National Animal Health Laboratory Network. Real-time reverse transcriptase-polymerase chain reaction (rRT-PCR) assay was used to detect the presence of both viruses. The technique uses specific primers designed to amplify a portion of the genome that

contains a target PCR sequence (Pedersen 2005; Pedersen 2007).

Statistical Analyses

We compared hematological and/or biochemical parameters (1) among years for AK, (2) within years for AK MAMU based on gender, sedations status, parasite status, nesting status, and females producing eggs vs. not, and (3) between CA and AK. Prior to each set of analyses, outliers were detected using range tests. Data were arranged in ascending order and any data point differing from the previous or proceeding point by more than one-third of the range was removed from the analysis (Petitclerc and Kelly 1981; Solberg 1981). Most blood results deviated from a normal distribution so non-parametric statistical tests were used unless stated otherwise. All statistical tests were conducted using SPSS 15.0. Statistical tests were considered significant at the 5% level of significance.

1) Hematological and Biochemical Comparisons among years for AK MAMU

We used Kruskall Wallis tests to determine whether significant differences existed among the three years of sampling (2005, 2006 and 2007) for total WBC, WBC differential cell counts, and H/L ratio. When significant differences were found among years for a parameter, we conducted post-hoc Mann-Whitney tests to determine which years were significantly different.

Using Kruskall Wallis tests, we examined differences in six biochemical parameters in AK MAMU for all years: glucose (GLU), calcium (CAL), phosphorous (PHOS), uric acid (URIC), total protein (TP), aspartate amino transferase (AST), alanine amino transferase (ALT), lactate dehydrogenase (LDH) and creatine phosphokinase (CPK).

2) Hematological and Biochemical Comparisons within years for AK MAMU

For years in which data were available, we performed univariate comparisons to detect differences in hematological and biochemical parameters based on five binary independent variables: male vs. female (2006 and 2007), sedated vs. non-sedated (all years), parasite presence vs. absence (all years), nesting vs. non-nesting (2007) and egg producing females at the time of

capture (2006 and 2007). Females with calcium levels above 12 mg/dL were considered to be breeding (Ivins *et al.* 1978) whereas females with CAL < 12 mg/dL were considered not to be producing eggs. In addition, we ran Mann-Whitney U tests to compare hematological and biochemical parameters grouped by two binary independent variables: males vs. females (2006 and 2007) and sedated vs. non-sedated (all years).

Parasite presence-absence refers to the detection of two types of avian blood parasites, *Haemoproteus* spp. or *Plasmodium* spp., on blood smears during differential WBC analysis (Fudge 2000). For 2007, breeding vs. non-breeding determination was based on movement patterns from radio transmitter data collected throughout the breeding season. MAMU observed flying inland and exhibiting an on-off pattern typical of nest incubation were considered breeders. For 2006 and 2007 birds, breeding females were separated from non-breeding females and males based on calcium levels in the blood (see above). All comparisons were made using a Mann-Whitney U test except for the 2007 WBC comparison between breeders/non-breeders, where a t-test was used.

In order to examine environmental conditions among years, air temperature data from NOAA's National Data Buoy Center was used to graph average monthly air temperatures for the past 20 years and for 2005, 2006, and 2007. Monthly precipitation levels from April – July for 2005 – 2007 are presented in Nelson *et al.* (2008).

3) Comparison between CA and AK

We compared WBC counts and seven biochemical analytes (GLU, CAL, PHOS, URIC, TP, AST and LDH) between CA and AK MAMU using Mann-Whitney U tests.

Results

Means and ranges for mass, culmen length, tarsus length, bill depth, wing chord and handling time are reported in Table 1. All values reported below are as mean ± SD.

1) Hematological and Biochemical Comparisons among years for AK MAMU

There was an overall difference in mean WBC among years in AK. Post-hoc tests revealed that mean WBC was significantly higher in 2007 (10,475 ± 4,380 cells/µl, n = 19) than 2005 (5,984 ± 4,753 cells/µl, n = 42) and 2006 (4,621 ± 3,355 cells/µl, n = 34) (Table 2). For differential white blood cell analyses, there were significant differences among years for eosinophils, heterophils, monocytes, and lymphocytes. Post-hoc results showed that for eosinophils, 2005 (6 ± 23 cells/µl, n = 42) was significantly lower than 2006 (325 ± 565 cells/µl, n = 34) and 2007 (189 ± 287 cells/µl, n = 19), which were not significantly different from each other. Monocytes and lymphocytes were significantly lower in 2006 (monocytes: 53 ± 78 cells/µl; lymphocytes: 1,133 ± 1,411 cells/µl, n = 34) than either 2005 (monocytes: 1,531 ± 1,482 cells/µl; lymphocytes: 2,298 ± 2,572 cells/µl, n = 42) or 2007 (monocytes: 2,339 ± 2,264 cells/µl; lymphocytes: 5,663 ± 4,107 cells/µl, n = 19) (Table 2).

The ratio of heterophils to lymphocytes (H/L) was significantly different for all 3 years, with the highest ratio in 2006 (4.50 ± 3.53, n = 34), followed by 2005 (1.86 ± 2.52, n = 42) and 2007 (0.60 ± 0.41, n = 19) (Table 2).

When biochemical parameters were compared, CAL, URIC, TP, ALT, and CPK values were significantly lower in 2005 (CAL: 9± 3 mg/dL, n = 38; URIC: 7± 2 mg/dL, n = 40; TP: 3.67 ± 0.621 g/dL, n = 35; ALT: 21± 13 U/L, n = 36; CPK: 28 ± 36 U/L, n = 37) compared to 2006 (CAL: 12 ± 7 mg/dL, n = 34; URIC: 13± 7 mg/dL, n = 35; TP: 4.35 ± 0.750 g/dL, n = 33; ALT: 85± 29 U/L, n = 33; CPK: 350 ± 331 U/L, n = 34) and 2007 (CAL: 16±9 mg/dL, n = 29; URIC: 15± 8 mg/dL, n = 29; TP: 4± 1 g/dL, n = 29; ALT: 72± 30 U/L, n = 28; CPK: 281± 211 U/L, n = 29), which were not significantly different from each other (Table 2).

We found significant differences in hematological parameters for gender between years. For males, WBC, monocytes and lymphocytes were significantly higher in 2007 (WBC: 10,463 ± 3,745 cells/µl; monocytes: 2,940 ± 2,677 cells/µl; lymphocytes: 4,983 ± 3,706 cells/µl, n = 11) than in 2006 (WBC: 3,490 ± 2,407 cells/µl; monocytes: 32 ± 35 cells/µl; lymphocytes: 845 ± 861 cells/µl, n = 16). Total WBC, monocytes, lymphocytes, and heterophils were significantly higher for 2007 females (WBC: 9,879 ± 5,540 cells/µl; monocytes: 1,179 ± 905 cells/µl; lymphocytes: 6,529 ± 5,063 cells/µl; heterophils: 1,935 ± 1,361 cells/µl, n = 7) than for 2006 females (WBC: 5,626 ± 3,803 cells/µl; monocytes: 72 ± 99 cells/µl; lymphocytes: 1,389 ± 1,751 cells/µl; heterophils: 3,652 ± 2,215 cells/µl, n = 18) (Table 3).

2) *Hematological and Biochemical Comparisons within years for AK MAMU*

There were no significant differences in hematological parameters comparing males and females using 2006 and 2007 data. For biochemical parameters, CAL, PHOS, and TP were found to be significantly higher for females (CAL: 18±9 mg/dL, n = 33; PHOS: 6±3 mg/dL, n = 34; TP: 5±1 g/dL, n = 33) than for males (CAL: 9±3 mg/dL, n = 29; PHOS: 2±2 mg/dL, n = 29; TP: 4±1 g/dL, n = 28). GLU, AST, ALT, and LDH were significantly lower for females (GLU: 307±30 mg/dL, n = 31; AST: 192±124 U/L, n = 29; ALT: 72±31 U/L, n = 33;LDH: 1,356 ± 1,036 U/L, n = 34) than for males (GLU: 334±39 mg/dL, n = 28; AST: 286±164 U/L, n = 29; ALT: 89 ± 25 U/L, n = 27; LDH: 1,937±1,596 U/L, n = 28) (Table 4).

Eosinophils, heterophils, H/L, CAL, URIC, ALT, and CPK were significantly lower for sedated birds (eosinophils: 70 ± 193 cells/µl; heterophils: 2,199 ± 1,559 cells/µl; H/L: 2.07±2.71, n = 67; CAL: 11 ± 6 mg/dL; n = 69; URIC: 9 ± 5 mg/dL, n = 70; ALT: 50 ± 36 U/L, n = 70; CPK: 175 ± 246 U/L, n = 70) compared to non-sedated birds (eosinophils: 364 ± 603 cells/µl; heterophils: 3,213 ± 2,147 cells/µl; H/L: 3.70 ±3.65, n = 28; CAL: 14 ± 8 mg/dL; n = 25; URIC: 17 ± 9 mg/dL, n = 25; ALT: 78 ± 33 U/L, n = 27; CPK: 292 ± 323 U/L, n = 25). Monocytes were significantly higher for sedated birds (1,331 ± 1,607 cells/µl, n = 67) than for non-sedated birds (764 ± 1,716 cells/µl; n = 28) (Table 5).

Blood parasites (*Haemoproteus* spp and *Plasmodium* spp) were present on 23%, 47%, and 36% of blood smears in 2005, 2006, and 2007, respectively. When birds with blood parasites from all three years were pooled and their hematological parameters compared to birds without blood parasites from all three years, eosinophils were significantly higher for birds with blood parasites present (282 ± 635 cells/µ, n = 27) than for birds without blood parasites (107 ± 208 cells/µ, n = 68), and monocytes were significantly higher for birds without blood parasites (1,263 ± 1,642 cells/µ, n = 68) than for birds with blood parasites (913 ± 1,679 cells/µ, n = 27). When biochemical parameters were compared, CAL, TP, ALT, and CPK were significantly higher for birds with blood parasites (CAL: 14 ± 8 mg/dL, n = 34; TP: 4.32 ± 0.76 g/dL, n = 33; ALT: 73 ± 33 U/L, n = 32; CPK: 340 ± 365 U/L, n = 33) than for birds without blood parasites (CAL: 11 ± 7 mg/dL, n = 67; TP: 4.02 ± 0.69 g/dL, n = 64; ALT: 50 ± 38 U/L, n = 65; CPK: 143 ± 172 U/L, n = 67) (Table 6).

Although 40 MAMU were marked in 2007, blood was collected from only 22 individuals, and of these, 11 made nesting attempts. Hematological and biochemical parameters were compared among confirmed breeders and non-breeders and no significant differences were found (Table 7).

When total WBC, differential WBC counts, and biochemical parameters for 2006 and 2007 females with CAL ≥ 12 mg/dL were compared to females with CAL < 12 mg/dL, total WBC and lymphocytes were significantly higher for birds with CAL ≥ 12 mg/dL (total WBC: 8,888 ± 5,310 cells/µl, n = 14; lymphocytes: 4,304 ± 4,519 cells/µl, n = 14) than for birds with CAL < 12 (total WBC: 4,006 ± 1,284 cells/µl, n = 10; lymphocytes: 813 ± 505 cells/µl, n = 10). For biochemical parameters, PHOS was significantly higher for birds with CAL ≥ 12 mg/dL (7 ± 2 mg/dL, n = 17) than for birds with CAL < 12 mg/dL (3 ± 2 mg/dL, n = 10) (Table 8).

All 2007 cloacal swab samples were negative for Avian Influenza Virus (AIV) and Newcastle Disease Virus (NDV).

3) Comparison between CA and AK MAMU

For AK MAMU, WBC (6,394 ± 4,697 cells/µl, n = 95), eosinophils (157 ± 386 cells/µl, n = 95), monocytes (1,164 ± 1,651 cells/µl, n = 95), lymphocytes (2,554 ± 3,087 cells/µl, n = 95), PHOS (4 ± 3 mg/dL, n = 102), TP (4.12 ± 0.73 g/dL, n = 97), and LDH (1,718 ± 1,327 U/L, n = 99) were significantly higher than WBC (3,709 ± 2,090 cells/µl, n = 82), eosinophils (4 ± 20 cells/µl, n = 82), monocytes (177 ± 295 cells/µl, n = 82), lymphocytes (704 ± 740 cells/µl, n = 82), PHOS (3.67± 3.79 mg/dL, n = 95), TP (3.29 ± 0.60 g/dL, n = 94), and LDH (245 ± 203 U/L, n = 94) for CA MAMU. Basophils and H/L were significantly lower for AK MAMU (basophils: 5 ± 21 cells/µl, n = 95; H/L: 2.55 ± 3.09, n = 95) compared to CA MAMU (basophils: 69 ± 113 cells/µl, n = 82; H/L: 13.90 ± 22.87, n = 78) than for (Table 9).

Discussion

Hematological and Biochemical Comparisons among and within years for AK MAMU

Total WBC is an indicator of immune system function which reflects the balance between

supply and need for white blood cells, or leukocytes, to defend the body against pathogens upon exposure and infection (Amand 1986; Raven and Johnson 2002; Hylton *et al.* 2006). Of the three years of this study, the average total WBC for 2007 birds was approximately twice the count of the previous two years. Birds were sampled in June 2005, in April 2006, and in May 2007. In 2006, PS MAMU experienced high mortality as did MAMU and KIMU in multiple locations in SE Alaska likely due to poor environmental factors that also limited breeding success. Contrary, May 2007 when birds were captured, was the height of the breeding season (Nelson 1997) and normal physiological processes associated with egg production in females may have played a role in the increased WBC count for 2007 MAMU. Egg production can result in antigen stimulation in females and cause increased WBC production. This hypothesis is also supported by our results comparing 2006 females to 2007 females. WBC for May 2007 females was significantly higher than WBC for April 2006 females and the higher female WBC likely elevated the overall MAMU mean WBC in 2007.

Not only was the total WBC value for 2007 higher than the other years, but eosinophil counts were significantly higher than 2005, and monocyte and lymphocyte counts were higher than 2006 and although not previously described, may be linked to the same breeding issues as WBC (see above).

In comparison to other studies, hematological reference ranges established for PS MAMU differed somewhat from studies on MAMU collected in the early 1990s from the Shumigan Islands, part of the Aleutian island chain in northeast Alaska (Newman *et al.* 1997) and Xantus' Murrelets (XAMU) from Santa Barbara Island, California (Newman *et al.* 2005). When we compare years separately, WBC counts from 2007 were higher than the above studies while hematological parameters from PS MAMU in 2005 and 2006 were similar (Table 10).

Monocytes were an order of magnitude higher for PS MAMU compared to MAMU from the Aleutian Islands and XAMU from California (both radio-marked and non-radio-marked). Monocytes are responsible for phagocytosis of foreign substances in the body. In our study, monocyte values did not differ between MAMU with blood parasites and those without blood parasites, but differences were observed between monocytes of PS MAMU. Although differences in total WBC and differential cell counts exist statistically, they are not of clinical or health significance. In fact, differences observed among these studies and cell types most likely represent differences in techniques used to conduct hematological analyses; WBC estimate

(Shumigan MAMU) versus the Natt Herick's (CA XAMU) versus Unopette technique (PS MAMU).

Stress associated with handling results in an increase of endogenous corticosteroids, resulting in transient heterophilia and lymphopenia (and therefore a higher H/L ratio). In birds, epinephrine levels can increase within seconds, and glucocorticoids can be secreted from the adrenal cortex within minutes which includes the handling time for MAMU in this study. If ecological conditions are good (abundant prey, seasonal temperature gradients, typical weather cycles of precipitation and sun, etc.), the stress response in murrelets should reflect only the stress associated with capture, handling and marking and therefore, the H/L ratio would in turn, reflect this "normal" stress associated with research techniques (Maxwell 1993; Newman *et al.* 2005).

H/L values for 2006 were significantly higher than 2005 and 2007. The cause of this high H/L ratio was a relatively low lymphocyte count despite an overall higher WBC for that year. This suggests that MAMU captured during 2006 were experiencing environmental stress in addition to the stress associated with capture and handling. This blood result further supports the fact that poor ecological conditions existed that year at the time of capture, and coincides with the significantly higher mortality rate observed in this year of the study compared to other years. H/L ratios for PS MAMU were higher than Aleutian Island MAMU sampled in the early 1990's, and interestingly, lower than California MAMU. In 2006, birds with high H/L ratios experienced high mortality and we believe that this is associated with difficult environmental conditions. Results form central CA MAMU suggest that ecological conditions in that habitat are likely having a significant effect on stress levels of birds. This may be part of the reason that breeding success of MAMU from central CA is approximately 50% in addition to limited nesting habitat, disturbance at nest sites, poor prey availability, or poor nutritional quality of prey (Perry *et al.* 2004).

Calcium was significantly lower in 2005 compared to the other two years. Calcium is an indicator of electrolyte and acid-base balance (Newman *et al.* 2005) and plays an important role in avian reproduction. For female birds, levels of CAL in the blood are known to increase when they near ovulation due to the estrogen-induced transport of yolk proteins to the ovary as CAL complexes (Dutton *et al.* 2002). This CAL, along with PHOS, are necessary for egg shell

formation and demand for CAL is so high, birds also have increased intestinal absorption of CAL and bones undergo demineralization to accommodate this physiological demand for CAL.

Lower CAL concentrations in 2005 were likely caused by the timing of sampling. In 2005, MAMU were sampled during post-breeding season, well beyond ovulation compared to birds sampled in April 2006 and May 2007 during breeding. Given that the mean year CAL is comprised of both male and female CAL levels, and given that male CAL levels do not fluctuate during the season, the differences measured are likely due to seasonal issues related to breeding in female MAMU.

Total protein is an indicator of liver function, nutritional status (Newman *et al.* 2005), and reflects protein synthesis and degradation (Hollmen *et al.* 2001). High TP values may be associated with dehydration, greater antibody production associated with chronic disease, and lipemia while low TP values may reflect malnutrition, inanition, hepatopathies, or chronic disease associated with malabsorption, chronic parasitism, and acute hemorrhage (Woerpel and Rosskopf 1984). The higher concentrations of TP in 2006 and 2007 may be associated with breeding season and specifically related to proteins (pre-albumin, albumin, and vitellogenin) produced by female birds in association with egg production. Although PS MAMU had slightly different TP concentrations than MAMU from the Aleutian Islands (Newman *et al.* 1997) and XAMU from California (Newman *et al.* 2005), all results are within clinically normal ranges.

Creatine phosphokinase is an enzyme associated with muscle function (Newman *et al.* 2007) and may be elevated due to physical exertion, traumatic restraint, or muscle atrophy secondary to poor environmental conditions leading to starvation and emaciation. Activity levels for this enzyme were highest for PS MAMU sampled in 2006. The spring of 2006 was particularly wet and cold leading to the suggestion that MAMU may have been under atypical environmental stress or increased metabolic demands leading to the elevated CPK levels measured after being captured and sampled. The average daily temperature recorded at the Juneau weather station in May 2006 was colder (9.4° C [48.9° F]), and wetter (21.59 cm [8.50 in] precipitation) than 20-yr averages (9.7° C [49.5° F] and 12.75 cm [5.02 in] precipitation; NOAA weather station, Junaeu AK). The extreme weather conditions in 2006 also could have played a role in the high number of mortalities observed in radio-marked PS MAMU that year (Nelson *et al.* 2008) as well as the poor breeding effort, in which only four radio-marked murrelets were detected inland in PS and two active nests were located and then failed.

CPK is often examined in conjunction with AST and LDH because extended capture and handling of birds can lead to capture myopathy resulting in elevated levels of one or more of these enzymes (Newman *et al.* 1997). Liver, heart, or muscle disease all result in increased AST and LDH. Elevations of CPK and LDH and not AST, as observed in PS MAMU, suggests non hepatic cellular damage and leakage, most likely from skeletal muscle.

Overall, LDH activity for PS MAMU was elevated in comparison to MAMU from California and the Aleutian Islands or XAMU from California. It has been determined that LDH rises and declines more rapidly upon muscle exertion in birds, followed by rising CPK and AST activity. Therefore, the high LDH activity serves as an indicator of physical exertion associated with a specific temporal marker of sampling approximately 30 min after capture. On the other hand, CPK activity was lower for PS MAMU in comparison to MAMU from California and the Aleutian Islands. Activity levels of CPK and AST were relatively low in PS MAMU and this suggests little, if any, prolonged muscle associated exertion due to capture or restraint.

Male vs. Female

No significant differences were found for hematological parameters between males and females in 2006, 2007, or when both years were pooled. This suggests that little variation in immune function and immunocompetence exists between the genders.

In both 2006 and 2007, WBC and CAL were significantly higher for female MAMU than for males. Higher levels of both of these health indices were expected due to physiological changes associated with breeding biology in female birds (see Hematological and Biochemical Comparisons among and within years for AK MAMU for details).

AST, ALT and LDH activity were significantly higher in males than females and this may be secondary to testosterone driven physiological adaptations that have resulted in increased muscle exertion upon capture and handling as compared to female birds.

2006- 2007 Females with Calcium ≥ 12 mg/dL vs. Females with Calcium < 12 mg/dL

Female MAMU from 2006 and 2007 were considered to be breeding if their CAL levels were 12 mg/dL or higher. The total WBC count for breeding females was more than twice the

values for non-breeding females, and the lymphocyte count for breeding females was more than five times the count for non-breeding females. This may come as a result of increased antigen production during egg-laying rather than be an indication of immune system compromise for breeding females.

Additionally, PHOS concentration was significantly higher for breeding females. Previous studies of avian reproduction found that during ovulation, PHOS increases in conjunction with increasing CAL values (Simkiss 1961). Phosphorus levels increase concurrent with bone demineralization that also provides additional CAL to female birds for egg shell production.

Sedated vs. Non-Sedated

The use of isoflurane to perform minor surgical procedures, particularly the attachment of radio transmitters, has been used on a variety of birds, including MAMU and XAMU in California (Newman *et al.* 1999), Surf and White Scoters in British Columbia, Canada (Iverson *et al.* 2006), and white-winged doves in Kingsville, Texas (Small *et al.* 2004). Sedation using isoflurane involves exposing birds to the gas from 30-60 sec and then removing the bird from the exposure mask. This results in reducing the stress associated with general bird handling and reduces stress and response to pain associated with the subcutaneous anchor transmitter attachment technique (Heatly *et al.* 2000; Newman *et al.* 2005).

When comparing hematological parameters of sedated birds to non-sedated birds (all years), eosinophils and heterophils were lower while monocytes were higher for sedated birds. Stress associated with handling results in an increase of endogenous corticosteroids within minutes of capture, and this in turn, results in transient heterophilia and lymphopenia. The fact that sedated birds had lower heterophil counts than non-sedated birds suggests that the sedation actually had an effect, and minimized the stress response, thus preventing the stress associated heterophilia. The reason for the changes in eosinophils and monocytes is unclear. Calcium, URIC, ALT and CPK were all significantly higher for non-sedated birds. Both ALT and CPK are enzymes related to muscle function and these particular enzymes are known to be elevated in response to struggling and physical exertion associated with birds being handled. Sedation proved to decrease the level of struggling and in turn, reduced levels of ALT and CPK. These

results support the idea that sedation is helpful in minimizing the stressful experience of capture, handling and transmitter attachment. Although the higher values of CAL and URIC may be associated to lower renal filtration if sedation was for a longer period of time (minutes), in this case, it is difficult to imagine that exposure to Isoflurane gas for 30-60 sec would result in these findings. Further analyses are needed to evaluate whether sedation has any impacts on likelihood of birds to nest and from data collected in 2006 and 2007, there does not appear to be any detrimental effect (lower nesting percentages in sedated birds) of radio marking birds using sedation.

Studies on manually restrained parrots have demonstrated that corticosterone concentrations were significantly higher than an anesthetized group of parrots implying that once sedated, the perceived threat and resultant stress that regulates corticosterone levels is impeded (Heatly *et al.* 2000). Newman *et al.* (2005) demonstrated that capture alone, was as stressful as capture and handling of birds, suggesting that if the stress response can be minimized as soon after birds are captured, this would be best for the birds in hand.

Nesting vs Non-Nesting 2007 AK MAMU

There were no significant differences in hematological and biochemical parameters between nesting and non-nesting MAMU sampled in 2007. The most obvious explanation for this is that both nesters and non-nesters consisted of approximately 50% male and 50% female birds and changes that would be expected due to birds nesting are most often linked to physiological changes in female birds. Although non-nesting birds were determined to be that based on radio telemetry data, it is possible that "non breeders" may have already laid eggs and nests failed, or abandoned nesting due to disturbance.

Blood Parasite Presence vs. Absence

Eosinophil counts were significantly higher for birds with blood parasites, *Haemoproteus* spp. or *Plasmodium* spp. Eosinophils are known to increase with infection by macroparasites (Ricklefs and Sheldon 2007), but do not routinely become elevated with intracellular parasitism. Lymphocytes on the other hand, have also been shown to increase in birds with detectable blood

parasites (Ricklefs and Sheldon 2007), and although a significant difference was not found for lymphocyte count, the mean was higher for birds with blood parasites. Both *Haemoproteus* spp and *Plasmodium* spp are hemosporidia, intracellular parasitic protozoans found in avian blood cells and tissues that are transmitted via numerous biting insects (Atkinson 1999). Hemosporidia cause avian malaria. Some avian families are more susceptible to avian malaria than others, with some species of hemosporidia causing severe anemia, weight loss and death (Atkinson 1999). Avian malaria is globally distributed, although it is thought to be absent or scarce in remote areas or areas with extreme climate conditions or salinity (Mendes *et al.* 2005). Although no studies to our knowledge have been done on the presence of avian malaria in Alaskan seabirds, one study that compared disease prevalence in migratory shorebirds from various habitat types found that the prevalence of avian malaria in birds from arctic regions was low in comparison to those from tropical regions (Mendes *et al.* 2005).

Calcium, ALT and CPK were significantly higher for MAMU with blood parasites present, but the reasons for these differences are unclear.

Disease analysis

PS MAMU were screened for Avian Influenza Virus (AIV) and Newcastle Disease Virus (NDV) in 2007 because these particular viruses pose threats to domestic poultry worldwide. Avian influenza has increased in importance due to the spread of highly pathogenic H5N1 strain that has killed several hundred people globally.

Avian Influenza is caused by type A influenza viruses. There are various AIV subtypes, classified by the combination of hemaglutanin (H) and neuraminidase (N) antigens. Wild avian populations of waterfowl are considered asymptomatic reservoirs (Hansen 1999) but seabird species such as MAMU have never been screened for these viruses.

Newcastle Disease is caused by infection from an RNA virus in the avian paramyxovirus-1 group. There are several strains of both high pathogenic and low pathogenic NDV. NDV is distributed worldwide, and more than 230 species of birds are susceptible to infection. Before 1990, NDV was primarily a concern for domestic poultry, but large-scale die-offs of Double-crested Cormorants in Canada and the United States in the 1990s made this a disease of concern for wild avian populations as well (Docherty and Friend 1999). A survey in the 1990s of NDV in

Alaskan and Siberian populations of waterfowl isolated 39 strains of NDV from the Alaskan populations (Takakuwa *et al.* 1998).

Neither disease was detected in any cloacal sample from MAMU in 2007 (100% negative). Because some migratory birds travel between Asia and Alaska, it is believed Alaska is a zone of Asia-to-America virus transfer (Winker *et al.* 2007). It is therefore possible for AIVs like H5N1 to be first detected in wild avian populations in Alaska. However, a 7-yr (1998-2004) AIV surveillance program in Alaska found low AIV infection rates (0.06%) in wild avian populations. The absence of the diseases in the birds we sampled suggest that MAMU in Alaska may have a low infection rate however continued monitoring of AIVs in Alaskan bird populations is important to further understand which viruses wild birds may be carrying form AK to the lower 48.

Comparison between CA and AK MAMU

Hematological and biochemical profiles have been used in other studies to reveal the geographic differences among stable and declining populations of seabirds (Hollmen *et al.* 2001). Thus, geographic comparisons of hematology and biochemistry may be useful in revealing differences between MAMU populations in PS AK which have remained relatively stable, and, MAMU populations in Año Nuevo Bay, CA which are steadily declining. The CA population of MAMU has been on the threatened species list in California since 1992 (USFWS 1992; Ralph *et al.* 1995), and the most recent survey has determined the CA population to still be in decline (Henkel and Peery 2008).

Total WBC, monocytes, eosinophils, lymphocytes and TP were lower for CA MAMU than for AK MAMU. Basophils and H/L were higher for CA MAMU, although the differences are not as striking or thought to be of clinical significance. However, hematological and biochemical values for AK MAMU were similar to reference ranges established for MAMU from the Aleutian Islands (Newman *et al.* 1997) and XAMU from California (Newman *et al.* 2005). The CPK activity for CA MAMU was almost twice that of AK MAMU, suggesting that CA MAMU may have experienced more stress as a result of capture and handling, including potentially poor environmental conditions

One factor that can compromise the avian immune system is pollution. The marine environment along the California coast may be affected by organic contaminants from agricultural run-off, trace elements discharged as waste from industrial areas, and oil pollution, and as a result, the health of MAMU populations in this area may be threatened. Further study to carefully evaluate MAMU health concurrent with contaminant levels in water, prey, and MAMU in central CA is necessary to draw such conclusions.

Conclusions

Hematological and biochemical parameters are useful tools for ecological research, providing insight about health of avian species such as their physiological state and organ function, pathology and possible disease and contaminant exposure (Newman *et al.* 2007). However, factors such as variation in species, sample collection techniques, capture methods, handling and storage of samples, and methods of analysis present difficulties in establishing hematological and biochemical reference ranges for a species (Drew *et al.* 1993; Low *et al.* 2006). Other factors that can affect hematological parameters include season, geographical location, ocean conditions, food availability, and photoperiod, (Newman *et al.* 1997). Also, enzyme activities and electrolyte concentrations can be influenced by age and sex of birds, body condition, diurnal cycles, and stage of breeding cycle (Martin *et al.* 1975).

In this study, we not only establish reference ranges for baseline blood health indices for MAMU in AK, but also identified significant differences between these parameters spatially, temporally and with respect to gender and parasite presence. Surprisingly, we found no significant differences in health parameters with regards to isoflurane use during handling and nesting activity. This will provide future AK MAMU health assessments to have information for comparative purposes and allows for continued monitoring of avian populations and ecosystem health over time. Currently, the MAMU sampled in our study appear to be healthy. However, they often face unpredictable environmental conditions during both their breeding and over-wintering seasons. Severe weather conditions may result in greater mortalities and breeding failure, as supported by the results of 2006. Other threats to MAMU health in PS include compromised water quality, contaminated prey items due to oil pollution, cruise ship discharges and discharges from industry, and changes in prey availability and abundance. However, the

current project has provided an opportunity to assess health of MAMU in PS at a time when no obvious health threats exist. This type of assessment, conducted before a problem or disaster occurs, is an excellent way to ensure a proper health assessments without complicating factors affecting interpretation of results and should be conducted more frequently to evaluate the health of populations of marine birds and other wildlife species.

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Table 1: Mean ± SD (sample size), range, minimum and maximum reported for morphometric measurements for AK MAMU sampled in 2005, 2006 and 2007.

	2005	2006	2007	All Years (2005-2007)
Mass (g)				
mean ± SD (n)	219 ± 19 (41)	236 ± 17 (40)	236 ± 27 (41)	227 ± 20 (106)
range	78	90	101	102
minimum	188	200	199	188
maximum	266	290	300	290
Culmen (mm)				
mean ± SD (n)	15.65 ± 0.89 (32)	15.03 ± 0.71 (40)	14.75 ± 1.24 (41)	15.11 ± 0.90 (97)
range	3.81	3.50	6.30	5.27
minimum	13.86	13.50	12.20	12.40
maximum	17.67	17.00	18.50	17.67
Tarsus (mm)				
mean ± SD (n)	21.32 ± 0.81 (32)	21.42 ± 0.84 (40)	18.63 ± 1.86 (41)	20.50 ± 1.80 (97)
range	4.26	3.60	7.80	7.14
minimum	18.78	19.20	15.90	15.90
maximum	23.04	22.80	23.70	23.04
Bill Depth (mm)				
mean ± SD (n)	6.33 ± 0.36 (32)	6.34 ± 0.52 (40)	6.47 ± 0.54 (41)	6.40 ± 0.49 (97)
range	1.30	2.10	2.30	2.30
minimum	5.65	5.60	5.60	5.60
maximum	6.95	7.70	7.90	7.90
Wing Chord (mm)				
mean ± SD (n)	132 ± 4 (32)	131 ± 4.41 (40)	134 ± 4 (41)	132 ± 4 (97)
range	17	23	16	26
minimum	124	115	126	115
maximum	141	138	142	141
Handling Time (min)				
mean ± SD (n)	70 ± 25 (43)	55 ± 19 (40)	56 ± 16 (36)	61 ± 22 (119)
range	88	78	64	101
minimum	35	26	22	22
maximum	123	104	86	123

Table 2: Mean ± SD (sample size), range, minimum, maximum and p-value reported for hematological and biochemical parameters for AK MAMU sampled in 2005, 2006 and 2007.

	2005	2006	2007	All Years (2005-2007)	p-value
WBC (cells/µl)					
mean ± SD (n)	5,984 ± 4,753 (42) B	4,621 ± 3,355 (34) B	10,475 ± 4,380 (19) A	6,394 ± 4,697 (95)	**0.0001**
range	19,697	17,304	15,886	19,697	
minimum	674	727	4,114	674	
maximum	20,371	18,031	20,000	20,371	
Eosinophils (cells/µl)					
mean ± SD (n)	6 ± 23 (42) **B**	325 ± 565 (34) **A**	189 ± 287 (19) **A**	157 ± 386 (95)	**0.0001**
range	123	3,190	1,002	3,190	
minimum	0	0	0	0	
maximum	123	3,190	1,002	3,190	
Heterophils (cells/µl)					
mean ± SD (n)	2,153 ± 1,764 (42)	3,046 ± 2,029 (34)	5,663 ± 4,107 (19)	2,498 ± 1,802 (95)	0.077
range	8,096	8,882	14,654	9,120	
minimum	256	494	946	256	
maximum	8,352	9,376	15,600	9,376	
Monocytes (cells/µl)					
mean ± SD (n)	1,531 ± 1,482 (42) **A**	53 ± 78 (34) **B**	2,339 ± 2,264 (19) **A**	1,164 ± 1,651 (95)	**0.0001**
range	7,619	361	6,984	7,680	
minimum	61	0	103	0	
maximum	7,680	361	7,087	7,680	
Lymphocytes (cells/µl)					
mean ± SD (n)	2,298 ± 2,572 (42) **A**	1,133 ± 1,411 (34) **B**	5,663 ± 4,107 (19) **A**	2,554 ± 3,087 (95)	**0.0001**
range	10,940	7,861	14,654	15,527	
minimum	196	73	946	73	
maximum	11,136	7,934	15,600	15,600	
Basophils (cells/µl)					
mean ± SD (n)	2 ± 15 (42)	8 ± 30 (34)	3 ± 13 (19) A	5 ± 21 (95)	0.232
range	99	162	56	162	
minimum	0	0	0	0	
maximum	99	162	56	162	
H/L ratio					
mean ± SD (n)	1.86 ± 2.52 (42) **B**	4.50 ± 3.53 (34) **A**	0.60 ± 0.41 (19) **C**	2.55±3.09 (95)	**0.0001**
range	13.97	13.54	1.29	14.13	
minimum	0.03	0.63	0.08	0.03	
maximum	14.00	14.17	1.38	14.17	
GLU (mg/dL)					
mean ± SD (n)	303±58 (36)	323±37 (30)	317±37 (30)	314±46 (96)	0.161
range	254	166	134	254	
minimum	198	270	261	198	
maximum	452	436	395	452	
CAL (mg/dL)					
mean ± SD (n)	9 ± 3 (38) **B**	12 ± 7 (34) **A**	16 ± 9 (29) **A**	12 ± 7 (101)	**>0.001**
range	17	29	28	31	
minimum	5	6	7	5	
maximum	22	34	36	36	

PHOS (mg/dL)					
mean ± SD (n)	4± 2 (38)	4± 3 (34)	4±3 (30)	4± 3 (102)	0.479
range	9	8	11	11	
minimum	1	1	1	1	
maximum	10	9	12	12	
URIC (mg/dL)					
mean ± SD (n)	7 ± 2 (40) **B**	13 ± 7 (35) **A**	15 ± 8 (29) **A**	11± 7 (104)	**>0.001**
range	14	29	36	36	
minimum	1	2	1	1	
maximum	15	31	37	37	
TP (g/dL)					
mean ± SD (n)	3.67 ± 0.62 (35) **B**	4.38 ± 0.76 (33) **A**	4.41 ± 0.99 (29) **A**	4.12 ± 0.73 (97)	**<0.001**
range	2.00	3.00	3.00	4.00	
minimum	3.00	3.00	3.00	3.00	
maximum	5.00	6.00	6.00	6.00	
ALT (U/L)					
mean ± SD (n)	21± 13 (36) **B**	85± 29 (33) **A**	72± 30 (28) **A**	58± 38 (57)	**<0.001**
range	59	133	102	152	
minimum	7	26	33	7	
maximum	66	159	135	159	
AST (U/L)					
mean ± SD (n)	277± 174 (38)	249± 170 (33)	220± 127 (26)	252± 161 (97)	0.487
range	787	655	417	787	
minimum	41	43	57	41	
maximum	828	698	474	828	
LDH (U/L)					
mean ± SD (n)	1,900± 1,308 (37)	1,546± 1,483 (33)	1,681± 1,169 (29)	1,718± 1,327 (99)	0.194
range	5,046	7,476	4,709	7,476	
minimum	522	448	550	448	
maximum	5,568	7,924	5,259	7,924	
CPK (U/L)					
mean ± SD (n)	28± 36 (37) **B**	350 ± 331 (34) **A**	281± 211 (29) **A**	208± 267 (100)	**>0.001**
range	216	1,534	719	43	
minimum	19	83	44	10	
maximum	235	1,617	763	53	

Table 3: Mean ± SD (sample size), range, minimum and maximum values reported for hematological and biochemical parameters of male and female AK MAMU sampled in 2006 and 2007. 2006 males were compared to 2007 males and 2006 females were compared to 2007 females, and p-values are reported.

	2006 females	2007 females	p-value	2006 males	2007 males	p-value
WBC (cells/µl)						
mean ± SD (n)	5,626 ± 3,803 (18) **B**	9,879 ± 5,540 (7) **A**	**0.034**	3,490 ± 2,407 (16) **B**	10,463 ± 3,745 (11) **A**	**<0.001**
range	16,243	15,886		8,313	12,144	
minimum	1,788	4,114		727	6,810	
maximum	18,031	20,000		9,040	18,954	
Basophils cells/µl)						
mean ± SD (n)	12 ± 40 (18)	8 ± 21 (7)	0.976	4 ± 11 (16)	0 ± 0 (11)	0.610
range	162	56		37	0	
minimum	0	0		0	0	
maximum	162	56		37	0	
Eosinophils (cells/µl)						
mean ± SD (n)	402 ± 731 (18)	228 ± 298 (7)	0.423	239 ± 286 (16)	168 ± 305 (11)	0.110
range	3,190	722		1,138	1,002	
minimum	0	0		0	0	
maximum	3,190	722		1,138	1,002	
Monocytes (cells/µl)						
mean ± SD (n)	72 ± 99 (18) **B**	1,179 ± 905 (7) **A**	**<0.001**	32 ± 35 (16) **B**	2,940 ± 2,677 (11) **A**	**<0.001**
range	361	2,201		114	6,701	
minimum	0	103		0	385	
maximum	361	2,304		114	7,087	
Lymphocytes (cells/µl)						
mean ± SD (n)	1,389 ± 1,751 (18) **B**	6,529 ± 5,063 (7) **A**	**0.001**	845 ± 861 (16) **B**	4,983 ± 3,706 (11) **A**	**<0.001**
range	7,720	14,654		3,449	12,252	
minimum	214	946		73	1,584	
maximum	7,934	15,600		3,522	13,836	
Heterophils (cells/µl)						
mean ± SD (n)	3,652 ± 2,213 (18) **A**	1,935 ± 1,361 (7) **B**	**0.047**	2,365 ± 1,606 (16)	2,372 ± 1,068 (11)	0.645
range	8,196	3,128		6,105	3,666	
minimum	1,180	672		494	694	
maximum	9,376	3,800		6,599	4,360	
GLU (mg/dL)						
mean ± SD (n)	315 ± 33 (17)	303 ± 31 (15)	0.370	336 ± 40 (14)	332 ± 40 (14)	0.839
range	113	98		153	121	
minimum	270	261		283	274	
maximum	383	359		436	395	
CAL (mg/dL)						
mean ± SD (n)	14 ± 8 (20) **B**	23 ± 9 (14) **A**	**0.017**	10 ± 3 (15) **A**	9 ± 3 (14) **B**	**0.009**
range	28	28		13	11	
minimum	6	8		8	7	
maximum	34	36		21	18	

PHOS (mg/dL)						
mean ± SD (n)	5 ± 3 (20)	7 ± 3 (15)	0.069	3 ± 2 (15)	2 ± 1 (14)	0.354
range	8	11		8	3	
minimum	1	1		1	1	
maximum	9	12		9	4	
URIC (mg/dL)						
mean ± SD (n)	15 ± 8 (20)	16 ± 9 (14)	0.569	11 ± 4 (15)	13 ± 6 (14)	0.310
range	24	36		15	23	
minimum	7	1		2	7	
maximum	31	37		17	30	
TP (g/dL)						
mean ± SD (n)	5 ± 1 (20)	5 ± 1 (14)	0.569	4 ± 1 (14)	4 ± 0 (14)	0.454
range	2	2		3	2	
minimum	4	4		3	3	
maximum	6	6		6	5	
ALT (U/L)						
mean ± SD (n)	77 ± 31 (20)	65 ± 32 (13)	0.207	98 ± 21 (13)	81 ± 27 (14)	0.061
range	133	102		71	94	
minimum	26	33		54	37	
maximum	159	135		125	131	
AST (U/L)						
mean ± SD (n)	188 ± 132 (18)	198 ± 115 (11)	0.611	323 ± 184 (15)	247 ± 126 (14)	0.290
range	431	286		630	417	
minimum	43	65		68	57	
maximum	474	351		698	474	
LDH (U/L)						
mean ± SD (n)	1,163 ± 509 (20)	1,683 ± 1,458 (14)	0.717	2,129 ± 2,112 (14)	1,744 ± 867 (14)	0.635
range	1,646	4,709		7,331	3,386	
minimum	448	550		593	706	
maximum	2,094	5,259		7,924	4,092	
CPK (U/L)						
mean ± SD (n)	335 ± 216 (20)	295 ± 202 (14)	0.416	364 ± 442 (15)	280 ± 230 (14)	0.949
range	830	604		1,534	719	
minimum	129	81		83	44	
maximum	959	685		1,617	763	

Table 4: Mean ± SD (sample size), range, minimum, and maximum values reported for male and female AK MAMU hematological and biochemical parameters when 2006 and 2007 data were combined. P-values are reported from statistical comparisons.

	Male	Female	p-value
WBC (cells/µl)			
mean ± SD (n)	6,331 ± 4,575 (27)	6,817 ± 4,660 (25)	0.602
range	18,227	18,212	
minimum	727	1,788	
maximum	18,954	20,000	
Eosinophils (cells/µl)			
mean ± SD (n)	210 ± 290 (27)	353 ± 638 (25)	0.402
range	1,138	3,190	
minimum	0	0	
maximum	1,138	3,190	
Heterophils (cells/µl)			
mean ± SD (n)	2,368 ± 1,388 (27)	3,171 ± 2,133 (25)	0.190
range	6,105	8,704	
minimum	494	672	
maximum	6,599	9,376	
Monocytes (cells/µl)			
mean ± SD (n)	1,217 ± 2,209 (27)	382 ± 685 (25)	0.503
range	7,087	2,304	
minimum	0	0	
maximum	7,087	2,304	
Lymphocytes (cells/µl)			
mean ± SD (n)	2,531 ± 3,163 (27)	2,828 ± 3,759 (25)	0.862
range	13,764	15,386	
minimum	73	214	
maximum	13,836	15,600	
Basophils (cells/µl)			
mean ± SD (n)	2 ± 9 (27)	11 ± 35 (25)	0.508
range	37	162	
minimum	0	0	
maximum	37	162	
H/L ratio			
mean ± SD (n)	2.81 ± 3.06 (27)	3.52 ± 3.78 (25)	0.687
range	13.21	14.08	
minimum	0.12	0.08	
maximum	13.33	14.17	
GLU (mg/dL)			
mean ± SD (n)	334±39 (28) **A**	307±30 (31) **B**	**0.005**
range	162	122	
minimum	274	261	
maximum	436	383	
CAL (mg/dL)			
mean ± SD (n)	9±3 (29) **B**	18±9 (33) **A**	**<0.0001**
range	14	30	

minimum	7	6	
maximum	21	36	
PHOS (mg/dL)			
mean ± SD (n)	2±2 (29) **B**	6±3 (34) **A**	**<0.0001**
range	8	11	
minimum	1	1	
maximum	9	12	
URIC			
mean ± SD (n)	12±5 (29)	16±8 (34)	0.071
range	28	36	
minimum	2	1	
maximum	30	37	
TP (g/dL)			
mean ± SD (n)	4±1 (28) **B**	5±1 (33) **A**	**0.016**
range	3	2	
minimum	3	4	
maximum	6	6	
AST (U/L)			
mean ± SD (n)	286±164 (29) **A**	192±124 (29) **B**	**0.035**
range	641	431	
minimum	57	43	
maximum	698	474	
ALT (U/L)			
mean ± SD (n)	89 ± 25 (27) **A**	72±31 (33) **B**	**0.017**
range	94	133	
minimum	37	26	
maximum	131	159	
LDH (U/L)			
mean ± SD (n)	1,937±1,596 (28) **A**	1,356±1,036 (33) **B**	**0.015**
range	7,331	4,811	
minimum	593	448	
maximum	7,924	5,259	
CPK (U/L)			
mean ± SD (n)	323±352 (29)	318±208 (34)	0.186
range	1573	878	
minimum	44	81	
maximum	1617	959	

Table 5: Mean ± SD (sample size), range, minimum, maximum and p-values reported for sedated and non-sedated AK MAMU for all years.

	Sedated	Non-Sedated	p-value
WBC (cells/µl)			
mean ± SD (n)	6,101± 4,744 (67)	7,095 ± 4,590 (28)	0.153
range	19,697	18,868	
minimum	674	1,132	
maximum	20,371	20,000	
Basophils (cells/µl)			
mean ± SD (n)	4 ± 16 (67)	7 ± 31 (28)	0.815
range	99	162	
minimum	0	0	
maximum	99	162	
Eosinophil (cells/µl)			
mean ± SD (n)	70 ± 193 (67) **B**	364 ± 603 (28) **A**	**<0.0001**
range	1,138	3,190	
minimum	0	0	
maximum	1,138	3,190	
Monocytes (cells/µl)			
mean ± SD (n)	1,331 ± 1,607 (67) **A**	764 ± 1,716 (28) **B**	**0.001**
range	7,680	7,087	
minimum	0	0	
maximum	7,680	7,087	
Lymphcytes (cells/µl)			
mean ± SD (n)	2,489 ± 2,824 (67)	2,708 ± 3,694 (28)	0.832
range	13,764	15,442	
minimum	73	158	
maximum	13,836	15,600	
Heterophils (cells/µl)			
mean ± SD (n)	2,199 ± 1,559 (67) **B**	3,213 ± 2,147 (28) **A**	**0.027**
range	8,096	8,704	
minimum	256	672	
maximum	8,352	9,376	
H/L			
mean ± SD (n)	2.07 ± 2.71 (67) **B**	3.70 ± 3.65 (28) **A**	**0.034**
range	14.13	13.25	
minimum	0.03	0.08	
maximum	14.17	13.33	
GLU (mg/dL)			
mean ± SD (n)	309 ± 47 (70)	325 ± 42 (26)	0.139
range	254	175	
minimum	198	261	
maximum	452	436	
CAL (mg/dL)			
mean ± SD (n)	11 ± 6 (69) **B**	14 ± 8 (25) **A**	**0.015**
range	29	30	
minimum	5	6	
maximum	34	36	
PHOS (mg/dL)			
mean ± SD (n)	3 ± 2 (69)	4 ± 3 (26)	0.825
range	9	11	

minimum	1	1	
maximum	10	12	
URIC (mg/dL)			
mean ± SD (n)	9 ± 5 (70) **B**	17 ± 9 (25) **A**	**<0.0001**
range	30	35	
minimum	1	2	
maximum	31	37	
TP (g/dL)			
mean ± SD (n)	4 ± 1 (69)	4 ± 1 (25)	0.096
range	5	3	
minimum	1	3	
maximum	6	6	
AST (U/L)			
mean ± SD (n)	248 ± 160 (71)	264 ± 169 (26)	0.687
range	787	655	
minimum	41	43	
maximum	828	698	
ALT (U/L)			
mean ± SD (n)	50 ± 36 (70) **B**	78 ± 33 (27) **A**	**0.001**
range	124	133	
minimum	7	26	
maximum	131	159	
LDH (U/L)			
mean ± SD (n)	1,682 ± 1,183 (70)	1,913 ± 1,740 (25)	0.645
range	5,066	7,476	
minimum	502	448	
maximum	5,568	7,924	
CPK (U/L)			
mean ± SD (n)	175 ± 246 (70) **B**	292 ± 323 (25) **A**	**0.002**
range	1,139	1,573	
minimum	10	44	
maximum	1,149	1,617	

Table 6: Mean ± SD (sample size), range, minimum, maximum and p-values of hematological and biochemical parameters reported for AK MAMU with blood parasites present on blood smears and for those without blood parasites (all years).

	Blood parasites present	Blood parasites absent	p-value
WBC (cells/µl)			
mean ± SD (n)	6,294 ± 5,305 (27)	6,434 ± 4,474 (68)	0.600
range	19,273	19,697	
minimum	727	674	
maximum	20,000	20,371	
Eosinophils (cells/µl)			
mean ± SD (n)	282± 635 (27) **A**	107 ± 208 (68) **B**	**0.030**
range	3,190	1,002	
minimum	0	0	
maximum	3,190	1,002	
Heterophils (cells/µl)			
mean ± SD (n)	2,444± 1,440 (27)	2,520 ± 1,936 (68)	0.668
range	6,207	9,120	
minimum	392	256	
maximum	6,599	9,376	
Monocytes (cells/µl)			
mean ± SD (n)	913 ± 1,679 (27) **B**	1,263 ± 1,642 (68) **A**	**0.038**
range	6,912	7,680	
minimum	0	0	
maximum	6,912	7,680	
Lymphocytes (cells/µl)			
mean ± SD (n)	2,643 ± 4,002 (27)	2,519 ± 2,674 (68)	0.448
range	15,527	10,940	
minimum	73	196	
maximum	15,600	11,136	
Basophils (cells/µl)			
mean ± SD (n)	1 ± 6 (27)	6 ± 25 (68)	0.481
range	30	162	
minimum	0	0	
maximum	30	162	
H/L ratio			
mean ± SD (n)	2.96± 3.23 (27)	2.39 ± 3.04 (68)	0.245
range	13.09	14.13	
minimum	0.24	0.03	
maximum	13.33	14.17	
GLU (mg/dL)			
mean ± SD (n)	323 ± 41 (32)	309 ± 48 (64)	0.099
range	222	254	
minimum	214	198	
maximum	436	452	
CAL (mg/dL)			
mean ± SD (n)	14 ± 8 (34) **A**	11 ± 7 (67) **B**	**0.011**
range	29	30	
minimum	6	5	
maximum	36	34	
PHOS (mg/dL)			
mean ± SD (n)	4 ± 3 (35)	4 ± 2 (67)	0.659

range	10	9	
minimum	1	1	
maximum	12	10	
URIC (mg/dL)			
mean ± SD (n)	12 ± 7 (34)	11± 7 (70)	0.055
range	30	36	
minimum	1	1	
maximum	31	37	
TP (g/dL)			
mean ± SD (n)	4.32 ± 0.76 (33) **A**	4.02 ± 0.69 (64) **B**	**0.025**
range	3.00	3.00	
minimum	3.00	3.00	
maximum	6.00	6.00	
AST (U/L)			
mean ± SD (n)	268 ± 186 (31)	245 ± 149 (66)	0.819
range	657	785	
minimum	41	43	
maximum	698	828	
ALT (U/L)			
mean ± SD (n)	73 ± 33 (32) **A**	50 ± 38 (65) **B**	**0.002**
range	116	152	
minimum	15	7	
maximum	131	159	
LDH (U/L)			
mean ± SD (n)	1,523 ± 1,255 (33)	1,815 ± 1,360 (66)	0.427
range	7,251	5,492	
minimum	673	448	
maximum	7,924	5,940	
CPK (U/L)			
mean ± SD (n)	340 ± 365 (33) **A**	143 ± 172 (67) **B**	**0.002**
range	1,607	717	
minimum	10	10	
maximum	1,617	727	

Table 7: Mean ± SD (sample size), range, minimum, maximum and p-values of hematological and biochemical parameters reported for 2007 nesting and non-nesting AK MAMU.

	2007 Nesting MAMU	2007 Non-nesting MAMU	p-value
WBC (cells/µl)			
mean ± SD (n)	10,527 ± 5,669 (6)	11,031 ± 3,975 (10)	0.635
range	14,442	14,840	
minimum	5,558	4,114	
maximum	20,000	18,954	
Eosinophils (cells/µl)			
mean ± SD (n)	114 ± 110 (6)	247 ± 375 (10)	0.875
range	269	1,002	
minimum	0	0	
maximum	269	1,002	
Heterophils (cells/µl)			
mean ± SD (n)	2,527 ± 1,145 (6)	2,180 ± 1,385 (10)	0.492
range	2,800	3,687	
minimum	1,000	672	
maximum	3,800	4,359	
Monocytes (cells/µl)			
mean ± SD (n)	1,564 ± 1,254 (6)	3,083 ± 2,838 (10)	0.562
range	3,440	6,984	
minimum	400	103	
maximum	3,840	7,087	
Lymphocytes (cells/µl)			
mean ± SD (n)	6,313 ± 4,933 (6)	5,521 ± 4,011 (10)	0.958
range	13,412	12,890	
minimum	2,188	946	
maximum	15,600	13,836	
Basophils (cells/µl)			
mean ± SD (n)	9 ± 23 (6)	0 ± 0 (10)	0.635
range	56	0	
minimum	0	0	
maximum	56	0	
H/L			
mean ± SD (n)	0.54 ± 0.42 (6)	0.60 ± 0.41 (10)	1.000
range	1.13	1.11	
minimum	0.24	0.08	
maximum	1.38	1.19	
GLU (mg/dL)			
mean ± SD (n)	303 ± 25 (10)	324 ± 40 (20)	0.169
range	83	134	
minimum	268	261	
maximum	351	395	
CA (mg/dL)			
mean ± SD (n)	16 ± 10 (10)	16 ± 9 (19)	0.839
range	28	24	
minimum	7	7	
maximum	36	31	
PHOS (mg/dL)			
mean ± SD (n)	5 ± 3 (10)	4 ± 3 (20)	0.846
range	9	11	
minimum	1	1	

maximum	10	12	
URIC (mg/dL)			
mean ± SD (n)	13 ± 7 (10)	15 ± 8 (19)	0.484
range	23	36	
minimum	7	1	
maximum	30	37	
TP (g/dL)			
mean ± SD (n)	4 ± 0 (10)	4 ± 1 (19)	0.542
range	2	2	
minimum	3	4	
maximum	5	6	
AST (U/L)			
mean ± SD (n)	±	±	0.339
range			
minimum			
maximum			
ALT (U/L)			
mean ± SD (n)	±	±	0.121
range			
minimum			
maximum			
LDH (U/L)			
mean ± SD (n)	1,554 ± 1,040 (10)	1,748 ± 1,254 (19)	0.769
range	3,542	4,553	
minimum	550	706	
maximum	4,092	5,259	
CPK (U/L)			
mean ± SD (n)	247 ± 171 (10)	299 ± 232 (19)	0.735
range	511	719	
minimum	69	44	
maximum	580	763	

Table 8: Mean ± SD (sample size), range, minimum, maximum and p-values of hematological and biochemical parameters reported for female AK MAMU from 2006 whose CAL was greater than or equal to 12 mg/dL and whose CAL was less than 12 mg/dL.

	Calcium ≥12 mg/dL	**Calcium <12 mg/dL**	**p-value**
WBC (cells/µl)			
mean ± SD (n)	8,888 ± 5,310 (14) **A**	4,006 ± 1,284 (10) **B**	**0.013**
range	18,212	3,736	
minimum	1,788	2,735	
maximum	20,000	6,471	
Eosinophils (cells/µl)			
mean ± SD (n)	535 ± 813 (14)	128 ± 117 (10)	0.138
range	3,190	362	
minimum	0	0	
maximum	3,190	362	
Heterophils (cells/µl)			
mean ± SD (n)	3,553 ± 2,521 (14)	2,710 ± 1,560 (10)	0.437
range	8,704	5,001	
minimum	672	823	
maximum	9,376	5,824	
Monocytes (cells/µl)			
mean ± SD (n)	391 ± 685 (14)	295 ± 709 (10)	0.75
range	2,045	2,304	
minimum	0	0	
maximum	2,045	2,304	
Lymphocytes (cells/µl)			
mean ± SD (n)	4,304 ± 4,519 (14)	813 ± 505 (10)	**0.013**
range	15,207	1,772	
minimum	393	214	
maximum	15,600	1,986	
Basophils (cells/µl)			
mean ± SD (n)	20 ± 46 (14)	0 ± 0 (10)	0.403
range	162	0	
minimum	0	0	
maximum	162	0	
H/L			
mean ± SD (n)	2.34 ± 2.48 (14)	5.40 ± 4.74 (10)	0.064
range	8.12	13.54	
minimum	0.08	0.63	
maximum	8.20	14.17	
GLU (mg/dL)			
mean ± SD (n)	299 ± 26 (17)	314 ± 32 (13)	0.213
range		113	
minimum	261	270	
maximum	358	383	
PHOS (mg/dL)			
mean ± SD (n)	7 ± 2 (9) **A**	3 ± 2 (10) **B**	**<.0001**
range		7	
minimum	2	1	
maximum	10	8	
URIC (mg/dL)			
mean ± SD (n)	16 ± 8 (17)	15 ± 9 (13)	0.536
range			

minimum	9	1	
maximum	37	31	
TP (g/dL)			
mean ± SD (n)	5 ± 1 (17)	5 ± 1 (13)	0.650
range		2	
minimum	4	4	
maximum	6	6	
AST (U/L)			
mean ± SD (n)	195 ± 131 (16)	188 ± 120 (13)	0.880
range	431	380	
minimum	43	54	
maximum	474	434	
ALT (U/L)			
mean ± SD (n)	66 ± 29 (20)	83 ± 33 (13)	0.087
range	102	133	
minimum	33	26	
maximum	135	159	
LDH (U/L)			
mean ± SD (n)	1,130 ± 510 (17)	1,748 ± 1,486 (10)	0.213
range	1,620		
minimum	474	448	
maximum	2,094	5,259	
CPK (U/L)			
mean ± SD (n)	334 ± 246 (9)	299 ± 185 (10)	0.837
range			
minimum	141	81	
maximum	959	727	

Table 9: Mean ± SD (sample size), range, minimum, maximum and p-values of hematological and biochemical parameters reported for AK MAMU (2005-2007) and CA MAMU (1997-2000).

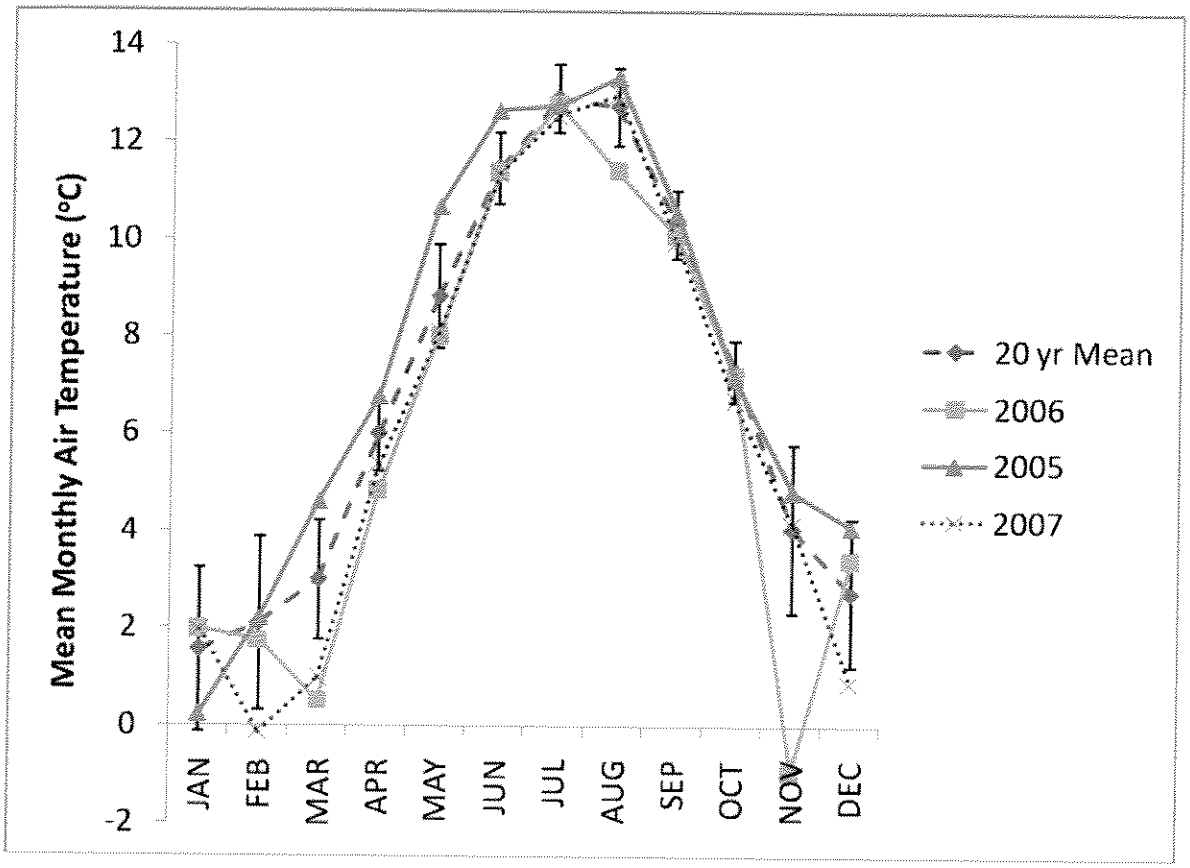
	Alaska MAMU	California MAMU	p-value
WBC (cells/µl)			
mean ± SD (n)	6,394 ± 4,697 (95) **A**	3,709 ± 2,090 (82) **B**	**<0.0001**
range	19,697	11,500	
minimum	674	500	
maximum	20,371	12,000	
Eosinophils (cells/µl)			
mean ± SD (n)	157 ± 386 (95) **A**	4 ± 20 (82) **B**	**<0.0001**
range	3,190	142	
minimum	0	0	
maximum	3,190	142	
Heterophils (cells/µl)			
mean ± SD (n)	2,498 ± 1,802 (95)	2,754 ± 1,800 (82)	0.236
range	9,120	9,170	
minimum	256	430	
maximum	9,376	9,600	
Monocytes (cells/µl)			
mean ± SD (n)	1,164 ± 1,651 (95) **A**	177 ± 295 (82) **B**	**<0.0001**
range	7,680	1,470	
minimum	0	0	
maximum	7,680	1,470	
Lymphocytes (cells/µl)			
mean ± SD (n)	2,554 ± 3,087 (95) **A**	704 ± 740 (82) **B**	**<0.0001**
range	15,527	2,925	
minimum	73	0	
maximum	15,600	2,925	
Basophils (cells/µl)			
mean ± SD (n)	5 ± 21 (95) **B**	69 ± 113 (82) **A**	**<0.0001**
range	162	468	
minimum	0	0	
maximum	162	468	
H/L			
mean ± SD (n)	2.55 ± 3.09 (95) **B**	13.90 ± 22.87 (78) **A**	**<0.001**
range	14.13	98.56	
minimum	0.30	0.44	
maximum	14.17	99.00	
GLU (mg/dL)			
mean ± SD (n)	314±46 (96)	334± 78 (93)	0.130
range	254	556	
minimum	198	228	
maximum	452	784	
CAL (mg/dL)			
mean ± SD (n)	12±7 (101)	12.17± 8.58 (95)	0.704
range	31	36.1	
minimum	5	6.5	

maximum	36	42.6	
PHOS (mg/dL)			
mean ± SD (n)	4.0 ± 3.0 (102) **A**	3.7± 3.8 (95) **B**	**0.049**
range	11	22.7	
minimum	1	0.5	
maximum	12	23.2	
URIC (mg/dL)			
mean ± SD (n)	11 ± 7 (95)	12 ± 6 (93)	0.250
range	36	26	
minimum	1	4	
maximum	37	30	
TP (g/dL)			
mean ± SD (n)	4.12 ± 0.73 (97)	3.29 ± 0.60 (94) **B**	**<0.0001**
range	4.00	2.7	
minimum	3.00	2.2	
maximum	6.00	4.9	
AST (U/L)			
mean ± SD (n)	252± 161 (97)	244 ± 123 (94)	0.832
range	787	581	
minimum	41	28	
maximum	828	609	
LDH (U/L)			
mean ± SD (n)	1,718± 1,327 (99) **A**	245 ± 203 (94) **B**	**<0.0001**
range	7,476	1,434	
minimum	448	48	
maximum	7,924	1,482	
CPK (U/L)			
mean ± SD (n)	208± 267 (100) **B**	489 ± 671 (93) **A**	**<0.001**
range	43	6,202	
minimum	10	37	
maximum	53	6,239	

Table 10: Comparison of hematological and biochemical parameters among MAMU from this study to MAMU from the Shumigan Islands and XAMU from California.

	MAMU from Port Snettisham	**MAMU from Shumigan Islands, AK (Newman *et al.* 1997)**	**XAMU from Santa Barbara Island, California (Newman *et al.* 2005)**	**Hematology for Radio-marked XAMU from Santa Barbara Island, California**
WBC (cells/µl)	6,394 ± 4,697 (95)	5,682 ± 1,999 (11)	6,274 ± 1,918 (60)	6,377 ± 2,490 (57)
Heterophils (cells/µl)	2,498 ± 1,802 (95)	1,477 ± 420 (11)	3,272 ± 1,835 (60)	4,604 ± 2,122 (56)
Lymphocytes (cells/µl)	2,554 ± 3,087 (95)	3,580 ± 280 (11)	2,543 ± 1,329 (60)	1,214 ± 1,077 (56)
Monocytes (cells/µl)	1,164 ± 1,651 (95)	57 ± 20 (11)	228 ± 216 (60)	314 ± 318 (56)
Eosinophils (cells/µl)	157 ± 386 (95)	511 ± 160 (11)	0 ± 0 (60)	3 ± 20 (56)
Basophils (cells/µl)**	5 ± 21 (95)	114 ± 60 (11)	160 ± 236 (60)	328 ± 113 (56)
GLU (mg/dL)	314 ± 46 (96)	228 ± 61 (8)	374 ± 85 (32)	N/A
CAL (mg/dL)	12 ± 7 (101)	1.2 ± 0.9 (8) MEQ/L	8 ± 0.7 (17)	N/A
TP (g/dL)	4 ± 1 (97)	4.9 ± 1.0 (9)	3.2 ± 0.4 (32)	N/A
AST (U/L)	252 ± 161 (97)	46 ± - (1)	287 ± 184 (32)	N/A
LDH (U/L)	1,718 ± 1,327 (99)	1,342 ± 720 (5)	396 ± 232 (31)	N/A
CPK (U/L)	208 ± 267 (100)	4,262 ± 893 (4)	46 ± 45 (31)	N/A

Figure 1: Mean monthly air temperature for Five Fingers light station (N 57° 16', W 133° 38') near Port Snettisham during the study years. Error bars on 20 yr mean represent the standard deviation.



At-sea Habitat Use and Patterns in Spatial Distribution of Marbled Murrelets in Port Snettisham, SE Alaska

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ABSTRACT

We examined prey availability, habitat use, and spatial distribution of Marbled Murrelets (*Brachyrhamphs marmoratus*, hereby MAMU) during the summer of 2007 in Port Snettisham (PS), AK. Strip transects revealed that MAMU were the dominant seabird species found on the water within our study area (93 % of all surveyed birds). We sampled MAMU prey using beach seining, plankton tows, and dip-netting, and found that capelin (*Mallotus villosus*;), Pacific sand lance (*Ammodytes hexapterus*), and other preferred forage fish species occurred in PS. All mixed forage flocks had MAMU present and capelin were the only prey item found in dipnet samples. The presence of adult, young of the year, and larval capelin suggested that PS was used by capelin as spawning habitat. Because of the high frequency of capelin found during prey sampling and their use of PS as spawning habitat, capelin were likely the primary prey item in the area for MAMU. When examining MAMU habitat use, we found that MAMU used different regions at night compared to those during the day, and this difference was not related to differing prey abundances. We modeled MAMU distribution at fine (100, 200, 400, 800, and 1600 m) and meso (14.2 km) scales using classification and regression tree (CART) analysis. At fine-scales, we examined MAMU abundance, number of MAMU groups, and presence-absence based on distance to creek, distance to shoreline, distance to flyway, mean depth, tidal slick count, prey target count (number of echo sounder targets), prey target sum (sum of echo sounder target pixels), and tidal stage. At almost all fine scales, distance to flyways was the most important variable with prey variables becoming more important as scale increases. However, CART models of fine scale habitat use did not perform well (e.g., at the 100 m scale the regression tree only explained 9.8% of the variance). At the meso-scale, we examined MAMU abundance and number of MAMU groups based on breeding period, tidal stage, time of day, prey target count, prey target sum, and tidal slick count. We found that low prey availability was associated with lower abundances of MAMU. However, we found that during low prey availability MAMU were more abundant during nest incubation and chick rearing compared with other breeding stages, suggesting MAMU remain close to nesting habitat during periods where inland flights are frequent. Models at meso-scale performed well explaining almost 50% of the variation. We used Ripley's K to examine spatial clustering by MAMU relative to each other (univariate) and their prey (bivariate). MAMU showed significant spatial clustering relative to one another on all transects with a patch length (scale of clustering) ranging from 0.3 to 9.0 km. Patch length increased significantly at the end of the breeding season (during late chick rearing/post breeding). For 18 of the 20 sample days MAMU were significantly clustered with prey, however, the scale of clustering showed high variation. Despite the high variation, MAMU tracked prey down to the finest scale of analysis (100 m) on 8 of the 18 days suggesting a generally high concordance. On days where MAMU group size was relatively high (>2 MAMU/group), MAMU tracked prey at a significantly finer scale and had significantly lower patch lengths suggesting that larger groups are more closely associated with fish and closer to other groups of MAMU. Comparing clustering characteristics among three different prey abundance categories (low, medium, high), we found MAMU tracked prey over a broader range of scales at medium relative prey abundances. Overall, these results add to the body of knowledge regarding how

MAMU use marine habitat during breeding season. Results provide information about temporal and spatial distributions of MAMU as well as prey occurrence in an area where breeding numbers are likely high relative to other regions across their range.

INTRODUCTION

The distribution of seabirds within the marine environment is strongly influenced by space and time. Spatially, the environmental and social factors that influence seabird distributions have been shown to be dependent on scale (Hunt and Schneider 1987, Swartzman and Hunt 2000) with seabirds likely making hierarchical decisions in selecting habitat (Fauchald *et al.* 2000, Becker and Bessinger 2003). For example, it would be expected that seabirds would show a strong aggregative response to their prey, however this is often not the case, especially at small scales (Swartzman and Hunt 2000, Fauchald and Erikstad 2002, Vlietstra 2005 and references therein). At larger scales, predators occupy the same general regions as their prey, however as scale becomes finer the spatial association between seabirds and prey becomes weak or highly variable (Fauchald and Erikstad 2002). At fine scales, associations between seabirds and prey are highly dependent on prey patch size (Davoren 2000) and prey abundance (Vlietstra 2005) which affect how seabirds track prey.

The Marbled Murrelet (*Brachyramphus marmoratus*, hereby MAMU) is a small alcid whose biology has received much attention due to their conservation status (USFWS 1992, McShane *et al.* 2004). The at-sea distribution of MAMU has been studied on a coast wide scale (Yen *et al.* 2004), and regional and local scales (Becker and Bessinger 2003). In this 2007 study we examine four aspects of the spatial distribution and habitat use of MAMU at-sea. First, we examined the effects of the diel cycle on MAMU distribution by comparing night and day survey values for different regions. Second, we use a multiscale approach to examine fine-scale MAMU distribution in relation to local habitat characteristics and prey distribution. Third, we use a 14.2 km section of transect to determine the effects of habitat characteristics as well as breeding period, tidal cycle and time of day on MAMU habitat use. And fourth, we used Ripley's K statistic (Ripley 1981), a measure of spatial clustering, to examine whether MAMU were clustered relative to one another and relative to echo sounder prey targets.

METHODS

Study Area

Port Snettisham (PS) is located about 40 km south of Juneau in Southeast Alaska (Figure

1). It is part of a large system of channels with fjord characteristics. It has a water surface area of approximately 80 km^2 and is surrounded by relatively intact old growth forest habitat. PS is relatively undeveloped except for a few small cabins, and a power station and fish hatchery located in the northeastern end of Speel Arm. PS's oceanography is strongly influenced by freshwater inputs from two major watersheds, the Speel and the Whiting Rivers, along with numerous perennial creeks. Strong tidal action mixes this freshwater with saltwater and it drains into Steven's Passage to the southeast. PS is located 150 km from the open ocean and is protected from oceanic circulation patterns by Admiralty and Chichagof islands.

Prey Sampling

We used three sampling methods to document possible MAMU prey items available in the study area: (1) dip-netting, (2) beach seining, and (3) plankton towing. Dip-net sampling was conducted opportunistically through the season (May 22-July 18 2007, N = 18). When forage flocks with MAMU were detected we approached the flock by boat, located the prey "balling" at the surface, and caught fish samples from the ball using a dip-net.

We beach seined at 14 different sites and sampled three of those sites twice. For the first portion of the season we used a beach seine 30.5 x1.8 m with a mesh size of 9.5 mm. Beginning on 14-July, we began using a smaller meshed beach seine with a knotless 4 mm stretch mesh net, 9.2 m in length with a 3.1 m centre that tapered to 1.1m at the wings. We conducted two beach seine replicates at each site at low tide. We sampled at low tide during the day because this is generally the most effective time to sample nearshore fishes (Haynes 2006).

Plankton tows were conducted in July 2007 in the same two transect sections that were sampled at night for MAMU (T14-T16 and T6-T9). Four sample points were placed at random along each transect section with the stipulation that they could not be closer than 500 m to each other. At each station, a small rectangular plankton net (45 cm x 25 cm, 500 micron mesh) was dropped to 50 m and towed obliquely for 5 minutes. T6-T9 was sampled twice and T15-T16 was sampled three times. Due to logistics of sampling at night during the summer when the time between sunset and sunrise is extremely short, we were able to sample plankton for T6-T9 and T15-T16 during the same night only once.

MAMU at-sea sampling

MAMU survey transects zigzagged from shoreline to shoreline and were oriented based on visible shoreline landmarks that aided in navigation. Surveys were conducted May – July 2007 in seas with a Beaufort sea state ≤ 3 and visibility across the water > 50 m. We sampled seabirds using a 100-m-wide fixed width strip transect in an 6.1 m aluminum hull vessel traveling at 14 $km \cdot h^{-1}$. One observer stood on each side of the bow (eye elevation approximately 2.5 m) of the vessel. Each observer used a digital voice recorder to record the number of birds sitting on the water along a 50 m line that ran perpendicular (abeam) to the vessel on their side of the boat. When birds flushed off the water due to the presence of the survey vessel, the observer noted their last location on the water and recorded the time when that location passed perpendicular to and within 50 m of the vessel. Periodically, we towed a buoy 50 m behind the vessel in order to aid the observers in estimating 50 m from the vessel. Birds within 2 m of each other were recorded as being in a group (Becker *et al.* 1997) and observers recorded a time for each single or group of birds. Birds in flight were not considered.

During our surveys observers noted the time the research vessel crossed a tidal disturbance (hereby referred to as "tidal slicks") into the digital recorder. Tidal currents can create physical structure in the water column that can be detected at the surface (Thomson 1981). For example, tidal disturbances can cause upwelling which is visible at the surface as smooth linear disturbances or downwelling which is visible at the surface as linear collections of debris (Holm and Burger 2002). Tidal disturbances are known to concentrate prey and foraging activity of diving seabirds has been associated with tidal structure (Decker and Hunt 1996, Holm and Burger 2002, Zamon 2003).

A third observer monitored a 200 kHz echo sounder (Model: Furuno FCV 585). The sounder screen was overlaid with a grid (5mm x 5mm grid size) and the depth scale was set to 0 – 60 m. For each target seen on the echo sounder during the survey, the third observer recorded the time the target appeared, target depth, bottom depth, target size (based on grid) and strength. Strength of the school target was scored as either strong (targets that showed at least a portion of the signal as the highest intensity) or weak (all other targets). Because we had a high number of weak targets that appeared to be due to halocline signal or other "noise", we only considered prey targets that were categorized as "strong" for analysis.

A GPS (Garmin 76cs) recorded time-stamped track points every 10 s during the survey.

After the survey, birds, tidal slicks, and echo sounder targets recorded by the observers were given a waypoint by associating the time of each observation with the track point closest in time. Thus, each spatial observation could be plotted along the linear transect in one-dimensional space.

Daytime surveys were collected over the entire study area (T1-T16, Figure 1) seven times through the season on a biweekly basis. We surveyed the section T6-T9 an additional 18 times (total of 25 T6-T9 surveys including the times surveyed with T1-T16). T6-T9 was sampled more frequently so we could better test the effects of the tidal cycle, time of day (TOD) and breeding period on the MAMU distribution. Low tide was classified as the 1 h period before and after the low tide (based on the mean low low water). High tide was classified similarly around the high tide (mean high high water). Rising and falling tidal stages were flow periods between low and high tide periods and the ebb periods between high and low tide periods, respectively. TOD was categorized as follows: (1) dawn (03:00:00-06:00:00 h); (2) morning (06:00:01-12:00:00 h); (3) afternoon (12:00:01-19:00:00 h); and (4) dusk (19:00:01-22:00:00 h). Based on telemetry data, we categorized the breeding season into three periods: (1) nesting initiation and incubation (25-May to 19-June); (2) incubation and chick rearing (19-June to 12-July); and (3) chick rearing and post breeding (begins 13-July).

We conducted night surveys in two regions: T15-T16 and T6-T9 (Figure 1) seven times in each region. These sections were chosen because when capturing MAMU at night for radio-tagging, section T15-T16 was found to have high numbers of MAMU aggregating (but not necessarily during the day), while T6-T9 was known to have high numbers during the day but night densities were unknown. Night surveys required the use of spotlights (1.5 million candlepower) that were fixed with straight aluminum tubing around the light face in order to focus the beam. Two observers, one on each side of the bow, scanned continuously using a 90° arc beginning in the direction of travel (*i.e.,* straight off the bow) to perpendicular to the direction of travel (*i.e.,* abeam off the port or starboard) and back. Birds were counted within a 50 m strip on either side of the vessel. We calibrated the 50 m distance estimate using the same buoy towed behind the boat as in the day. Bird and sounder data were recorded in the same manner as during day surveys.

Statistical analysis

Night Surveys

We used paired sample t-tests to compare MAMU/km between T6-T9 and T15-T16 for both night and day, and to compare MAMU/km for T6-T9 day versus night and T15-16 day versus night. We made the same comparisons for echo sounder prey target count and prey target sum to explore possible spatial and diurnal prey differences. We also compared depth of prey targets between night and day using a Mann-Whitney U test (the non-parametric equivalent of the student's t-test).

Fine-scale habitat use

We examined MAMU distribution at one extent (T1-T16, Figure 1) but at five different linear lengths or scale "grains": 100, 200, 400, 800, 1600 m. The entire 100 m wide transect was split into bins the length of each scale grain. MAMU abundance (number of individual MAMU) and MAMU group count (number of MAMU groups) as well as eight independent habitat variables were summarized for each bin at each scale. All spatial data manipulation and extractions were done in ArcGIS 9.2 (ESRI).

MAMU abundance and MAMU group count were analyzed in relation to eight independent variables: distance to creek, distance to shoreline, distance to flyway, mean depth, tidal slick count, prey target count, prey target sum and tidal stage. Distance to nearest creek, shoreline and major flyway were taken as the linear distance from the bin centroid to the feature (*i.e.,* shoreline, creek, flyway). The three most important flyways for MAMU traveling inland to nesting habitat were determined through radio telemetry as Speel River, Whiting River, and Gilbert Bay (Figure 1). The distance to the flyway entrance from each bin was calculated. Depth for the entire transect was calculated from sounder data taken over the entire season and interpolated using Inverse Distance Weighting (IDW). Mean depth was the average depth for the bin area. Tidal slick count is the number of visible disturbances in the water surface created by currents or tidal upwelling recorded in each bin. Prey target count was the number of targets seen on the echo sounder per bin while prey target sum was the sum of the pixels (based on the grid over the display screen) for all targets in each bin. Tidal stage for the bin was categorized as the stage (rising, high, falling or low, as described above) at the time the bin was surveyed. We standardized the dependent and independent count variables by area because bins were not

exactly equal in area (note: "distance to" and tidal stage variables did not require standardization). In addition to the continuous dependent variables, we also classified bins into MAMU presence-absence.

Univariate analysis – We explored univariate relationships at the 100 m bin scale. We examined Spearman's correlation coefficients (r_s) between continuous variables and examined the relationship between MAMU presence-absence and the independent variables using Mann-Whitney U tests.

CART analysis – We analyzed MAMU distribution with respect to environmental characteristics using Classification And Regression Tree (CART) methods. Classification trees use constraints rather than correlates to analyze data (O'Connor 2002), which is more realistic in the context of habitat selection or use (Huston 2002). Thus, classification trees are likely to be more robust compared with traditional techniques that rely on linear correlations such as Generalized Linear Models (GLM's). Also, classification trees deal automatically with non-pamametric data, interaction effects, non-linear predictors, and spatial autocorrelation. These concerns can confound GLM's by causing a violation of assumptions (O'Connor 2002, Muñoz and Felicísimo 2004). All CART associated statistical analyses were conducted in SPSS (Version 15.0).

We ran preliminary CART analyses to determine the importance of each dependent variable in relation to MAMU distribution at the five different scales for each dependent variable: MAMU presence-absence, MAMU abundance, and MAMU group count. At each spatial scale, ten trees were grown for each dependent variable. Bins were not averaged across dates for analysis. Each tree subsampled approximately 250 points randomly from each dataset. Bivariate CART analysis can be affected by the presence-absence ratio (*i.e.*, high proportions of absence counts, De'ath and Fabricius 2000). To compensate for deviations in the 50:50 presence to absence ratio for each bin size we used a weighted influence variable to account for differences in the presence to absence ratio (Ronconi 2008). Trees were grown using the Gini impurity measure with a liberal minimum improvement of 0.00001 and no pruning (to induce growth), a maximum tree depth of five, and a minimum of 10 cases in a parent node and 5 cases in the child node in order for growth to continue. Importance values for independent variables were calculated as the weighted sum across all tree nodes of the improvements that an independent variable has when it is used as a primary or surrogate splitter (Breiman *et al.* 1984).

We then built one final tree at the 100 m bin size for each dependent variable using bin values averaged across dates for each variable (i.e., each bin has only one value for each variable based on average values from the seven surveys). Averaging bins temporally decreases the sample size but helps maintain spatial independence of points. The tidal stage variable was not included because its values could not be averaged. We designated MAMU as present if they were present in the bin more times than the mean number of times MAMU were present in all bins for that scale and absent if they were present in the bin less times than the mean. Trees were built using the same methods as above but were pruned using the 1-standard deviation rule (Breiman *et al.* 1984). We used 80% of the data to build the trees (training set) and cross-validated using the remaining 20% (test set).

Meso-scale habitat use

We used a 14.2 km section of the transect (T6-T9, Figure 1) to test the relationship for both MAMU abundance and MAMU count with breeding period, tidal stage, time of day, prey target count, prey target sum and tidal slick count. This section was sampled 25 times throughout the season and the entire section was treated as the scale grain for the mesoscale analysis of habitat use.

Univariate analysis – We examined Spearman's correlation coefficients (r_s) between continuous variables. We compared mean MAMU abundance per transect among breeding periods, TOD, and tidal stage using Kruskal-Wallis tests. We compared mean MAMU abundance per transect in relation to the four TOD categories. We also collapsed categories into 1) dawn/morning (03:00:00-12:00:00 h) and 2) afternoon/dusk (12:00:01-22:00:00 h) and compared MAMU count, MAMU abundance, prey target count, and prey target sum between these two time periods using a Mann-Whitney U test. Similarly, for tidal stage we compared mean MAMU abundance per transect in relation to four stages: low, rising, high and falling (described above). We also grouped the four categories into (1) slack (low and high tide periods), and (2) rise-fall (rising and falling tide periods), and compared mean MAMU count per transect (Mann-Whitney U test).

CART analysis – We ran a regression tree analysis for each of the two continuous dependent variables (MAMU abundance and MAMU group count) at the scale of the entire T6-T9 transect (N = 25). The tree was grown in the same manner as above.

Spatial Scale of Clustering

The Ripley's K statistic (Ripley 1981) tests whether spatial distributions of points depart from a random distribution to a clustered (aggregated) or regular spatial distribution (Cornulier and Bretagnolle 2006). The K statistic can be used to describe whether spatial clustering exists and at what scales. Details of this statistic and its uses have been described elsewhere (*e.g.*, Ripley 1981, O'Driscoll 1998, Burger *et al.* 2004, Wiegand and Maloney 2004).

Univariate - We calculated Ripley's K in MatLab (R2007B) using routines developed by O'Driscoll (1998) for all transects, and we compared patch length and crowding values among the three transect types using a Kruskal-Wallis test. The MAMU transects were relatively long and narrow so we treated data as one-dimensional rather than two-dimensional to avoid large edge effects. We did not control for spatial heterogeneity because we were simply interested in detecting clusters rather than explaining why clusters occur.

We compared patch length and crowding among breeding periods using a Kruskal-Wallis test for transects T6-T9. Outliers were defined as values more than twice the standard deviation, and were filtered from the analysis.

To examine the effect of prey abundance on the spatial distribution of MAMU, we divided prey target sum into three categories (low <5.26, medium 5.26-9.75, and high >9.76) and prey target count into three categories (low <2.0, medium 2.0-2.49, and high >2.5) and used a Kruskal-Wallis test to detect differences in crowding and patch length for each dependent variable.

Bivariate - In addition to the univariate analysis, we ran a bivariate K statistic analysis of MAMU distribution with relation to depth sounder targets. Bivariate routines were based on O'Driscoll (1998). Target signals below 40 m were removed because beyond this depth fish would generally be inaccessible to diving MAMU (Burger *et al.* 2004).

We examined four parameters that describe how MAMU track prey for each survey date: (1) minimum scale of aggregation; (2) patch length; (3) crowding; and (4) spatial range of aggregation. The minimum scale of aggregation is the first scale at which aggregation is higher than the 99% confidence interval defined by a Monte-Carlo technique. Thus, the minimum scale of aggregation is the finest significant scale that MAMU can track prey. The patch length, or characteristic spatial scale of clustering, is defined as the first significant peak of clustering and represents the distance between significant clusters. We used the approach of O'Driscol *et al.*

(2000) and defined the first peak as the scale at which crowding was higher than the next 3 succeeding values to avoid labeling small jumps as peaks. Crowding is a measure of the aggregation (the number of MAMU in the patch) at that scale. Spatial range of aggregation is defined as the distance (based on the number of 100 m intervals) where aggregation is significantly clustered out of a total of 14,400 m (total length of the transect) and represents the range of scales that MAMU track prey.

We compared the four parameters describing MAMU spatial distribution (minimum scale of aggregation, patch length, crowding, and spatial range of aggregation) based on six independent variables: MAMU abundance, MAMU group count, prey target count, prey target sum, and mean MAMU group size (defined as MAMU count divided by MAMU groups) and breeding period. Data were not normally distributed so we used non-parametic routines to test for significant differences. A Kruskal-Wallis test was used to detect differences between multiple groups, and a Mann-Whitney test between two groups. If the Kruskal-Wallis test was significant, a Mann-Whitney test was used post-hoc to identify which values differentiated themselves in a pair-comparison. All groups were defined using 50% percentile for two groups and 33% percentiles for three groups, except breeding periods (defined above, Table 1). Only prey target sum was split into three groups, to detect if there was a maximum response at medium values, as suggested by Vlietstra (2005).

RESULTS

We sampled 8,890 birds on the at-sea strip transects with MAMU making up 93% of all bird species observed (Table 2). MAMU were predominantly found in pairs (Figure 2).

Prey Sampling

We caught ten fish species and four zooplankton prey types within the study area that are known MAMU prey items (Table 3).

We dip-netted fish at 20 forage flocks with MAMU present during the season (mean MAMU count per flock = 23, SD = 21). All prey sampled in the forage flocks were adult capelin (*Mallotus villosus*; mean fork length = 84.3 mm, SD = 13.8 mm).

Based on beach seine surveys of nearshore areas, high proportions of juvenile salmonids

were present in the nearshore including: Chum (*Oncorhynchus keta*), Pink (*Oncorhynchus gorbuscha*), Chinook (*Oncorhynchus tshawytscha)*, Sockeye (*Oncorhynchus nerka*), and Coho (*Oncorhynchus kisutch*). Out of all the fish sampled by beach seine, 29% were salmonid species (mean length = 65 mm, SD = 23 mm) and salmonids were present at 12 of the 14 sites sampled. When we switched to a beach seine with smaller mesh size on 14-July we began catching newly recruited Pacific sand lance (*Ammodytes hexapterus*; 4 sites, N = 37, mean fork length = 48.5 mm, SD = 4 mm) and capelin (2 sites, N = 36, mean fork length = 36 mm, SD = 7 mm).

Plankton samples showed high variation and sample sizes were not high enough to test whether there were significant differences in euphausid and amphipod concentrations between T6-T9 and T15-T16 (Table 4). The high variation seen may be a result of the short nights, which resulted in rapid change of light levels over the sampling period.

Night Sampling

There was variability in MAMU distributions at night by region and significant differences in abundance between night and day (Figure 3). Comparing sections at night, T15-T16 had a significantly higher MAMU abundance/km than T6-T9 ($t = -3.618$, $DF = 4$, $P = 0.022$), however there were no significant differences between the two sections during the day ($t = -1.821$, $DF = 5$, $P = 0.128$). Comparing directly between day and night samples for each section, T6-T9 had significantly higher counts during the day ($t = -6.536$, $DF = 5$, $P = 0.001$) while T15-T16 had higher counts at night, however this difference was not significant ($t = 2.572$, $DF = 4$, $P = 0.062$).

There were no significant differences in echo sounder target count or pixel sum per km between the T6-T9 and T15-T16 at night (count: $t = 0.266$, $DF = 4$, $P = 0.803$; sum: $t = 2.456$, $DF = 4$, $P = 0.070$). Comparing between night and day, T6-T9 had significantly higher sounder target count and target pixel sum per km in the day than at night (count: $t = -3.644$, $DF = 4$, $P = 0.022$; sum: $t = -5.098$, $DF = 4$, $P = 0.007$). T15-16 sounder target count and pixel sum did not differ significantly between day and night periods (count: $t = -1.016$, $DF = 4$, $P = 0.367$; sum: $t = -1.199$, $DF = 4$, $P = 0.297$). Fish schools were significantly shallower at night ($U = 2567$, $Z = -5.104$, $P < 0.001$; Figure 4).

We also observed large numbers of fish breaking the surface of the water as the spotlight passed over, appearing as though the light startled fish at the surface. This phenomenon was

commonly seen throughout the night transects, most frequently near the shoreline. We dipnetted one sample of fish (N=3) exhibiting this behavior and identified them as capelin.

Fine-scale habitat use

Univariate analysis – Both MAMU abundance and group count were negatively correlated to depth, and distance to shoreline, creeks and flyways (Table 5). Prey target variables were also negatively correlated with distance to shoreline, creeks, and flyways. MAMU presence-absence showed similar relationships with independent variables (Table 6, Figure 5).

CART analysis – Distance to flyways was the most important variable for almost every scale for each dependent variable (Figure 6). For the continuous dependents (MAMU count and MAMU group count), flyways became less important at the 1600 m scale and distance to other creeks became the most important variable. Prey target size and prey target count became more important as bin size increased.

The final tree for MAMU abundance at the 100 m bin scale didn't produce any nodes and therefore did not grow. The trees for MAMU group count and MAMU presence-absence grew two and eight nodes, respectively (Figure 7). These trees show similar results as the analysis of importance values. For both trees, the first split was based on distance to flyways, on a split of approximately 9.5 km. There were more MAMU groups and MAMU were present more often within approximately 9.5 km from the major flyways. The MAMU group count tree terminated without any further splitting, however the MAMU presence-absence tree was split further with distance to creeks. The univariate analysis showed MAMU group count to be negatively correlated with distance to creeks (i.e., MAMU group count was higher closer to creeks). The classification tree showed that for MAMU close to flyways there were a higher proportion of MAMU present at a distance greater than 2 km from the nearest creek. Node 3 was further split based on depth with MAMU present in higher proportions in shallower water (bins with mean depth <655 m). Node 5 was further split with the distance to flyways variable with MAMU again being present in higher proportions closer to major flyways (bins < 3.1 km from flyways). Generally, splits closest to the parent node (node 0) are the most generalizable (Rejwan *et al* 1999). Although the presence-absence tree is grown beyond the first split, the improvements to the overall model from subsequent splits were far less (an order of magnitude less) than the first split and should be interpreted with caution.

Assessing the performance of trees built for the 100 m bin scale, the regression tree built with MAMU group count performed extremely poorly explaining only 9.3% of the variance. The classification tree showed a 72.3% classification rate based on the test sample.

Meso-scale habitat use

Univariate analysis – There were no significant correlations between independent and dependent continuous variables other than the expected correlations between MAMU abundance and group count; and prey target sum and count (Table 7). There was a significant difference in mean MAMU count per transect among breeding periods (DF = 2, N = 23, H = 9.7652, P = 0.008, Figure 8). Post hoc comparisons showed that the chick rearing and post-breeding period had significantly lower counts than incubation and chick rearing period (Z = 3.1192, P = 0.005).

There was no overall difference in mean MAMU count per transect among the four TOD categories (Chi-square = 4.896, df = 3, P = 0.108), however, when TOD was grouped into two categories there was a significant difference in MAMU counts between Dawn/Morning and Afternoon/Dusk (Z = -2.195, P = 0.028; Figure 9). There were no significant relationships detected between Dawn/Morning and Afternoon/Dusk and prey target count (U = 38.5, Z = -0.7329, p = 0.473) and target sum (U = 41.0, Z = -0.5401, p = 0.624).

There was a significant overall difference in MAMU abundance per transect among tide heights (Kruskal-Wallis, H = 8.647, N = 45, P = 0.034), however post hoc comparisons among tide heights did not show any significant paired differences. When tidal stage was grouped into two categories, there was a significant difference in MAMU abundance per transect between slack and rising/falling (U = 28.0, Z = -2.0656, P=0.040; Figure 10). There was also a significant difference in prey target sum when comparing between these two tidal categories with slack tide having significantly higher prey target sum compared to rise/fall (U =5.0, Z = -3.2203, P = 0.001; Figure 10). No significant relationship was found between prey target count and the collapsed tidal stages (U =27.5, Z = -1.3660, P = 0.177).

CART analysis – Both MAMU abundance and MAMU group count trees were first split based on prey target sum with MAMU being more abundant and having higher group counts on transects where prey target sum was high (Figure 11). When the prey target sum was higher, there was almost double the number of MAMU/km compared to when it was low (21 MAMU/km compared to 11 MAMU/km). Note that prey target sum are values based on specific

equipment and collection protocol, thus values cannot be directly compared to other studies. Although both trees were split on similar values of the same variable, the improvement to the MAMU abundance tree was much higher compared to the improvement to the MAMU group count tree. The MAMU abundance tree was further split based on breeding period which again showed a relatively large improvement value. When breeding period was (1) nest initiation and incubation or (2) incubation and chick rearing, numbers of MAMU in T6-T9 were higher compared to (3) chick rearing and post breeding.

Between the two regression trees, the tree for MAMU abundance performed the best explaining 48.9% of the variance in the training dataset while the regression tree for MAMU group count explained 24.5% of the variance.

Spatial Scale of Clustering

Univariate - All transects showed significant clustering in the distribution of MAMU (Table 8). The three different transect types showed slightly different values for patch length and crowding, however these differences were not significant (patch length Chi square = 4.06, P = 0.131; crowding Chi square = 4.02, P = 0.134).

There was no significant difference in crowding among breeding periods (DF = 2, N = 21, H = 2.214, P = 0.331), however there was a significant difference in patch length (DF = 2, N = 20, H = 7.229, P = 0.027). Post hoc comparisons showed that the chick rearing and post-breeding period (category 3) had a significantly higher patch length than the nest initiation and incubation period (category 1, z = 2.684, P = 0.007) and incubation and chick rearing period (category 2, z = 2.052, P = 0.040). There was no significant difference between nest initiation and incubation period and the incubation and chick-rearing period.

Prey target count per transect (range = 0.75-5.25, mean = 2.5, SD = 1.26) yielded no differences in crowding (DF = 2, N = 19, H = 0.599, P = 0.741) or patch length (DF = 2, N = 19, H = 0.283, P = 0.868) among high, medium, and low categories. Prey target sum per transect (range = 1.88-49.05, mean = 10.81, SD = 10.60) likewise yielded no differences in crowding (DF = 2, N = 19, H = 0.942, P = 0.624) or patch length (DF = 2, N = 19, H = 0.642, P = 0.725).

Bivariate – MAMU showed temporal and spatial inconsistency in tracking prey. We found significant aggregation of MAMU in relation to fish schools on 18 out of 20 days (Figure 12). On 8 out of these 18 days, the MAMU was significantly aggregated around fish school

down to the smallest sample size of 100 m, indicating that MAMU can track fish schools down to our finest scale of analysis. Two transects showed no significant aggregation of MAMU relative to fish distribution. The 16 July transect only had significant aggregation above the halfway mark of the transect and was ignored, as edge effects makes interpretation difficult for the last half of the analysis (see O'Driscoll *et al.* 2000). The 23 July transect had no significant values for the entire transect. These two transects were removed from further analyses.

Days with high mean MAMU group size (*i.e.*, more MAMU in a group on average) had significantly lower minimum scale (*i.e.*, the smallest scale at which MAMU can track fish) compared to days with low mean MAMU group size (Table 9, Figure 13). Days with high mean MAMU group size also had significantly lower patch length (Table 9, Figure 14). When comparing among relative prey densities, days with medium values for prey target sum yielded a significantly larger range of aggregation than low and high values which did not differ significantly from each other (Figure 15).

DISCUSSION

Prey Sampling

Capelin were the only prey present in the mixed-species forage flocks observed in PS. MAMU in the forage flocks were seen foraging directly around capelin concentrated at the surface. Anecdotally, forage flocks were commonly seen in our study region. If the majority of those flocks were feeding on capelin as our data suggest, then capelin may be the main prey item for MAMU in PS. Capelin form spawning congregations in nearshore regions of Alaska during late spring/summer (Arimitsu *et al.* 2007, 2008) and inhabit cooler waters with lower primary productivity compared to Pacific herring (*Clupea pallasii*) and sand lance. These concentrations of capelin are known to support predator populations during periods when predators are energetically constrained (Womble *et al.* 2005). If capelin use PS as a spawning region, they may occur at high enough concentrations to provide MAMU with a reliable source of high caloric content prey throughout the breeding season. The presence of larval and newly settled capelin likely indicated spawning activity (Brown 2002). In PS we found capelin larvae (40 ± 7 mm) in beach seine and plankton tow samples as well as newly settled and adult capelin in the dipnet

samples of forage flocks. The use of PS as a spawning region for capelin may be a major reason why MAMU occur there in relatively high densities during breeding.

Salmonids were found in high frequency in the beach seine samples and were often noted schooling very close to shore (within 1 - 3 m of water depth) within PS. At the mouth of Speel River there is a salmon hatchery. The release of juvenile salmonids from this hatchery may cause elevated concentrations in the nearshore. Salmonids have been found in the diets of MAMU and because of their ubiquity in the nearshore in our study region, they are likely taken as prey items. However, because we have no direct measures of MAMU diet, we have no evidence of this.

Compared to abundances in other regions (*e.g.*, Speckman *et al.* 2003, Arimitsu *et al.* 2007, Haynes *et al.* 2007, Haynes *et al.* 2008), sand lance were not found in high abundances in PS. Because sand lance are the most important prey item for MAMU across their range, it is likely that, if they occur in high enough abundances, they would be an important prey item in this region. Sand lance are often found in high abundances in nearshore waters associated with specific sediments found in the intertidal and subtidal regions (Ostrand *et al.* 2005, Haynes 2007, 2008). We sampled all shorelines that could be sampled with a beach seine, however we only found a total of 74 sand lance at seven sites from 17 sampling events. Because sand lance can be associated with substrate in deeper subtidal regions (Wright *et al.* 2000, Holland *et al.* 2005), it is possible that finding low abundance of sand lance in our study area using beach seining is related to sand lance use of deep subtidal rather than shallow subtidal and intertidal substrates in PS. However, when schooling in the water column, sand lance are most often in shallower waters (*e.g.*, <40 m, Ostrand 2005) and can be commonly found in waters <12 m deep (Haynes 2007). Thus, even if sand lance were using deeper substrates for burying in PS, they should have been found in our forage flock samples. Areas where sand lance are more common in Alaska (Robards *et al.* 1999, Speckman *et al.* 2003, Ostrand *et al.* 2005, Arimitsu *et al.* 2007) and in British Columbia (Haynes 2007, 2008) generally have more shallow nearshore regions and/or beach habitat available. Thus, the lack of abundant sand lance in our study area may be due to the deeper fiord habitat of PS lacking suitable intertidal and shallow subtidal habitat that sand lance use for burying or spawning.

We did not detect newly recruited sand lance during the beginning of the season, however when we switched to a beach seine with smaller mesh size newly recruited sand lance and capelin showed up in the beach seine samples. Thus, it is likely that the original beach seine

used did not detect newly recruited sand lance and capelin because they could pass through the mesh. The presence of newly recruited sand lance suggests that recruitment of larval sand lance occurs to some degree in PS. However, if this recruitment was substantial we would have likely seen considerably more of the larger size classes of sand lance in samples from both beach seines.

Other species known to be preyed upon by MAMU were found in the study region such as Pacific sandfish (*Trichodon trichodon*), dolly varden (*Salvelinus malma malma*), walleye pollock (*Theragra chalcogramma*), and zooplankton species (euphausides, amphipods, mycids and chaetognatha). The presence of these species is important to document, however the relative importance of the different prey types is difficult to assess without further investigation. Pacific herring were notably absent in PS based on our sampling and are unlikely to be found within our study region (D. Csepp pers. comm. 2008). Herring have been found to be extremely important for MAMU in other regions of AK (*e.g.*, Kuletz 2005) and are considered one of the most important prey items for MAMU across their range (Burkett 1995).

Night Sampling

MAMU utilized habitat differently in day and night periods. T6-T9 had significantly higher MAMU abundance during the day compared to at night. Thus, MAMU may utilize this region as a daytime feeding area but leave this region at night. T15-T16 had a similar MAMU abundance to T6-T9 during the day, however it had a significantly higher MAMU abundance at night. Also, T15-T16 had higher (but not significantly higher) MAMU abundance during the night compared to the day suggesting that MAMU move into this region during night hours (this was documented by data loggers and visual surveys in PS by Newman *et al.* 2005, Nelson *et al.* 2006). Thus, at night MAMU moved from the inside protected region (T6-T9), which is utilized during the day, to the mouth of PS (T15-T16).

Very little is known about alcid spatial distribution and behavior at night. Using telemetry, Jodice and Collopy (1999) and Peery (pers. comm. 2008) found that MAMU in Oregon and California, respectively, did not dive at night. In Auke Bay, Whitworth *et al.* (2000) noted MAMU moving away from shore and into deeper waters nightly. TBH also observed that MAMU moved out of channels to deeper open waters at night in Desolation Sound, British Columbia. In a study where eight Rhinocerous Auklets (*Cerorhinca monocerata*) were fitted

with time-depth dataloggers during breeding season, 98% of dives took place between 03:00 – 20:00 h (Kuroki *et al.* 2003). Conversely, a study on thick-billed murres in the Canadian arctic showed that the majority (65-68%) of dives occurred between 20:00 – 4:00 h (Croll *et al.* 1992). Because the dives were significantly shallower during the night, Croll *et al.* (1992) suggest that the murres may be tracking diurnally migrating prey.

If MAMU are foraging during the night, MAMU may redistribute themselves in response to a diurnal change in prey abundance. We did not find significant differences in echo sounder values of prey target count or prey target sum between regions suggesting that differences in the distribution of MAMU between regions at night were not due to differences in fish prey availability between the two regions. When comparing within regions, T15-T16 did not differ between night and day, however T6-T9 had higher target count and pixel sum during the day. This suggests that fish schools become less abundant in the T6-T9 region during the night which may explain why MAMU abundance also decreases in this region at night if they are foraging nocturnally. However, we consistently observed large numbers of fish breaking the surface of the water as the light passed in the T6-T9 region. The high abundance of fish (likely capelin) at the surface during night hours along with the significantly shallower prey targets on the echo sounder suggest that capelin move to surface waters during the night. If capelin are very close to the surface at night they would not be seen on the echo sounder. Thus, the reduced number of prey targets in the T6-T9 region at night may be explained by capelin moving up to the surface, thus going undetected by the echo sounder. Paired sampling for euphausids for the two regions was inconclusive because sampling was limited. Thus, we are unable to say whether distribution of MAMU at night corresponded to fish or zooplankton prey being more abundant in certain regions.

There are other possibilities to why MAMU redistribute at night including energetic, social, and other behavioral factors. For example, moving to the mouth of PS may provide MAMU with open water where they can loaf on the water to rest without risk of drifting into shore or as a means for avoiding predation. A significant part of MAMU ecology has been built around predator avoidance including, but not limited to, their cryptic plumage, crepuscular inland flights, and secretive behavior at nest sites (Nelson and Hamer 1995). Some MAMU are thought to move to offshore wintering grounds just before their pre-basic molt (Carter and Stein 1995); this could be associated with avoiding predation in addition to finding locations with

readily available prey. If MAMU are not foraging at night or avoiding predation in these nightly breeding season movements, they could be gathering for social interaction with other murrelets in the area. Speckman *et al.* (2003) suggested that many of the behavior patterns of MAMU (displaying, pair bonding, choosing mates, foraging) are socially facilitated. Certainly, more research is needed to determine the mechanisms that drive MAMU offshore at night in Southeast Alaska.

Although we compared day to night counts directly, the survey techniques are obviously different due to night surveys requiring the use of spotlights. Night surveys may underestimate the number of MAMU due to higher levels of undetected birds. During day transects, MAMU that flush before the vessel can be easily seen from a long distance away. At night, the distance illuminated by the beam of the spotlight does not allow the detection of birds that flush at as great a distance. However, MAMU are less likely to flush at night which makes MAMU captures possible at night but not during the day (Whitworth *et al.* 1997). Thus, numbers counted at night may be comparable to day surveys.

Fine-scale habitat use

At the various scales of analysis, the most important variable to MAMU distribution was distance to flyways, with MAMU remaining close to major flyways. MAMU fly inland to nest sites often multiple times per day depending on the breeding stage (highest during chick rearing; Nelson 1997). MAMU use marine regions adjacent to inland flyways as staging grounds for their inland flight and thus congregate in these regions (Nelson 1997).

Examining CART trees from the 100 m bin scale, MAMU were more likely to be found within approximately 9.5 km of the flyways and the number of MAMU groups were higher within this distance as well. A range of 9.5 km from each major flyway encompasses a large portion of the study area, therefore MAMU may just be staying on the "inside" of PS and not using the area close to Steven's Passage. However, the further split of the presence-absence tree at 3.1 km further narrows the area around the flyways suggesting that MAMU are remaining close to major flyways rather than flyways being a surrogate for an inside-outside effect.

All three major flyways in this study were also estuarine areas. Yen *et al.* (2004) found that MAMU were positively correlated with estuarine habitat on a coast-wide scale. They suggest that this positive correlation arises because of the unique aquatic characteristics that

estuaries provide for MAMU. Although this may be the case, estuaries may also be areas where MAMU congregate because estuaries provide entrances to major watersheds which in turn provide natural flyway corridors through inland terrain to nesting habitat (*e.g.*, Burger 1997). Thus, in addition to using estuaries for foraging habitat, MAMU are found close to estuaries during breeding because they are used as staging grounds for inland flights.

Although distance to flyways was generally the most important variable, as the scale increased to 1600 m flyways became far less important for the continuous dependent variables. For both MAMU group count and MAMU abundance, distance to creeks became the most important variable, followed by prey target size. Based on the classification tree for MAMU presence-absence for the 100 m bin scale, MAMU were more likely to be present at distances greater than approximately 2 km from the nearest creek. Thus, the tree shows that there may be an interaction effect between creeks and flyways. This is opposite to the univariate analysis results that showed that MAMU were found closer to creeks. Distance to creeks was significantly correlated with distance to flyways (*i.e.,* flyways also were major watersheds and therefore were also considered "creeks"). Thus, the univariate negative correlation between MAMU abundance and group count and distance to creeks may be related to the covariance of distance to creeks with distance to flyways.

The increase in importance of prey measures as the scale increases show the difficulty of linking seabird distributions with prey data at fine scales. Other studies have shown that it is difficult to make associations between seabirds and hydroacoustic prey data at fine scales of analysis (Fauchald *et al.* 2000, Fauchald and Erikstad 2002).

The regression tree for MAMU group count at the 100 m bin scale explained only 9.3% of the variation and the tree for MAMU abundance failed to grow at this scale. This suggests that variables used in the modeling process lacked the ability to explain MAMU habitat use patterns based on "count" data (*i.e.,* MAMU abundance or group count). Abundance models have generally been less precise than occupancy models given the inherent difficulties in modeling count data (Stauffer 2002). The classification tree model for MAMU presence-absence performed better with the tree classifying 72.3% of the bins correctly for the test dataset. However, considering that the data used to build the model had a presence-absence ratio of approximately 50:50, a model which chose to classify all sites as either "present" or "absent" would have a 50% classification rate. Thus, the classification tree had a classification

improvement of 22.3% compared to a model that classified all bins as only one of the binary categories.

Meso-scale habitat use

Prey target sum was the most important variable at the meso-scale for both MAMU abundance and MAMU group count. Although prey target count and prey target sum were not important at the fine scale analysis, the importance value analysis showed that they became more important as the bin size became larger (increase in scale). Thus, it is more likely that prey target count or sum would be important at this larger scale of analysis.

Breeding season was the second most important variable in the MAMU abundance tree. When prey target sum was low, MAMU were more abundant during nest initiation, incubation, and chick rearing compared to after 13-July when chick rearing was finished for many birds and post-breeding dispersal began. Based on telemetry data, PS has three important flyways and numerous more minor flyways into nesting regions. When MAMU are incubating and feeding chicks, they must remain close to the inland nesting areas. Thus, MAMU using nesting habitat in PS remain within the study area even when prey availability is low. When MAMU enter post-breeding, they are no longer required to remain close to the nest and can forage elsewhere when prey availability is low in the region. Becker and Bessinger (2003) found that MAMU stayed close to nesting habitat when prey availability was high and moved to cooler waters ("higher quality foraging habitat") when prey availability was low. During breeding, we also found low prey availability was associated with lower MAMU abundances (as mentioned above), however, the interaction effect between low prey availability and breeding stage suggests that MAMU still remain close to nesting habitat when prey abundance is low during breeding season. MAMU are energetically constrained and thus may be less likely to make longer trips to find better foraging habitat. However, MAMU may remain around PS for other reasons, for example, to stage for inland flights after having foraged elsewhere thus accounting for the differences between the breeding and post breeding periods.

Due to the inherent noise of the systems, modeling abundance data in ecology can be difficult (Stauffer 2002). This being considered, the model of MAMU abundance for T6-T9 performed extremely well, with the regression tree based on two independent variables explaining almost 50% of the variation. The ability to explain this amount of variation suggests

that at this scale, unlike the finer scales examined above, prey data from echo sounder recordings (coupled with the variation explained by seasonal effects, i.e. breeding period) are useful in describing MAMU abundance. It is important to point out that although models performed well, trees were built based on only 25 survey days (N = 25) which is a low sample size for CART analyses.

The foraging activity of piscivorous seabirds has been linked to tidal cycles (Holm and Burger 2002, Zamon 2003). The nature of the relationship between the tidal cycle and seabird foraging is likely dependent on the specific physical characteristics of the region as well as the bird species being studied (*e.g.,* Holm and Burger 2002). Although tidal stage was not selected in the tree analysis, it was found to be related to MAMU abundance in the univariate analysis. MAMU were found to be more abundant in the surveys at slack tide compared to rising/falling tide. Holm and Burger (2002) found similar results with piscivorous seabirds preferring slack or moderate tidal currents to forage. Speckman *et al.* (2000) also found that MAMU numbers peaked during slack tides, but they also increased during falling morning tides in Auke Bay, AK. The increase in MAMU abundance during slack tide was also accompanied by significantly higher prey abundance. The tidal cycle likely makes prey more available by concentrating prey and providing favorable foraging conditions (Holm and Burger 2002).

Spatial Scale of Clustering

Univariate - Results from Ripley's K can reveal spatial structure and thus give guidance to appropriate scales of study (O'Driscoll 1998). At the smallest spatial scale MAMU are known to forage mainly in pairs during breeding season (McFarlane Tranquilla *et al.* 2003), which was also seen in this study. At the scale of kilometers, Ripley's K analysis revealed that MAMU clustering was highly variable with patch length ranging from 300 m to over 9 km. Mean patch length was between 1.84 and 3.96 km depending on the transect, which is slightly higher than the value reported by Burger *et al.* (2004) of 1 ± 0.9 km.

Patch length increased significantly during post-breeding. After breeding, MAMU are no longer energetically or spatially constrained (*i.e.,* not required to make inland flights), and consequently, it would be expected that the end of breeding would be accompanied by a change in behavior that would likely be reflected in their at-sea distribution. The increase in patch length after breeding suggests that MAMU groups are foraging further from one another. MAMU were

found near flyway areas in the meso-scale habitat analysis. During post-breeding, flyways are likely less important and thus MAMU groups can be distributed more evenly within the study area, thus increasing patch length.

No distinction was made between first order and second order clustering in this analysis. Instead, we were interested in determining whether clustering existed and at what scales. Thus, variations in the clustering of MAMU may be a result of a response to variations in environmental characteristics (first order) or may reflect variations in interaction behavior among MAMU such as competition or social groupings (second order; Cornulier and Bretagnolle 2006).

The Ripley's K statistic assumes that all sample counts along transects be taken from the same statistical distribution, independent of time and space (O'Driscoll 1998). This assumption of stationarity is likely not the case because seabirds distribute themselves relative to rapidly changing environmental conditions. However, in a similar spatial analysis of seabird distributions, O'Driscoll (1998) assumed that the seabird distribution was weakly stationary as was the case in this study. Because, as in most seabird transects, transects here are essentially spatially 1-dimensional (*i.e.,* long and narrow), patch length and clustering are not true measures of overall patch dimensions. Also, we did not perform any edge correction and thus higher patch length are likely less accurate than low values (O'Driscoll 1998).

Bivariate - Seabirds are known to congregate at areas with high prey concentration (Fauchald and Erikstad 2002, Piatt *et al.* 2006). However, studies have had little success linking the distribution of seabirds to the distribution of their prey (*e.g.*, Hunt *et al.* 1992, O'Driscoll 1998, Fauchald *et al.* 2000). Those that have linked seabird distributions to prey distribution have found that the existence of the relationship has been temporally inconsistent (*e.g.*, Schneider and Piatt 1986, Wright and Begg 1997, Vlietstra 2005). For example, Burger *et al.* (2004) found that pooled alcids (including MAMU) were significantly associated with prey during 67 % of the transects based on a Ripley's K analysis. We found both spatial and temporal inconsistency with regards to MAMU tracking prey. Although inconsistent, MAMU generally tracked prey at some scale on each study day (18 of the 20 days) and tracked prey down to the finest scale of analysis (100 m) for 8 of those 18 days. Although variation exists, this suggests a relatively close temporal-spatial relationship between MAMU and their prey.

Swartzman and Hunt (2000) found that larger clusters of murres (*Uria* spp.) and puffins (*Fratercula* spp.) were more consistently associated with prey. Their results suggest a positive

relationship between size of the cluster (*i.e.*, number of birds in a "group") and the strength of the association with prey. In our study MAMU were most commonly found in groups of two. However, on days when MAMU formed larger groups (greater than a mean of 2.33 MAMU/group) the groups were associated with prey at a finer scale (smaller minimum scale of aggregation). This finer scale of aggregation suggests that when MAMU are in larger groups they may be more closely tracking prey. This result was accompanied with a significantly smaller patch size on days where the mean MAMU group size was greater than two (>2.33 MAMU/group). Because large groups were more closely associated with fish schools, they were more likely to be close to each other (shorter patch length).

We found significant differences in the scales over which MAMU can track their prey which appears to be related to prey abundance. MAMU appeared to track prey over the largest range of scales (*i.e.*, spatial range of aggregation) when moderate levels of prey are available. This fits the non-linear relationship described by Vlietstra (2005). When prey is very abundant, it is not energetically efficient to track the prey, and birds might employ a "sit-and-wait" approach. At intermediate prey levels, birds would be expected to distribute themselves according to ideal free distribution, displaying a high concordance between prey and predator. However, at even lower levels, constraints can arise that limit a predator's ability to track prey such as competition or lack of information on prey patches (Vlietsra 2005). It is noteworthy that although MAMU have a larger range of aggregation when prey is at moderate levels, they do not track prey at significantly finer scales.

ACKNOWLEDGMENTS

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Tables:

Table 1. Definition of independent variables for statistical analysis.

Parameter	Definition	Categories
MAMU abundance	Sum of birds observed	High (204+ birds)
		Low(<=203 birds)
MAMU group count	Sum of groups of birds observed	High(83.51+ groups)
		Low(<=83.50 groups)
Mean MAMU Group Size	MAMU abundance/MAMU group count	High(2.34+ MAMU/group)
		Low (<=2.33 MAMU/group)
Prey target count	Sum of prey target count	High (8.51+ targets)
		Low (<=8.50 targets)
Prey target sum	Sum of prey target sum	Low (<24.5 pixels)
		Med(24.51 – 41.00 pixels)
		High(41.01+ pixels)
Breeding Periods	Based on date of transects	See Methods

Table 2. Summary of species composition from at-sea transects in Port Snettisham.

Species	Number of birds	%
Marbled Murrelet (*Brachyramphus marmoratus*)	8236	92.64
Unidentified Gull Species (*Larus spp.*)	308	3.46
Surf Scoter (*Melanitta perspicillata*)	118	1.33
Pigeon Guillemot (*Cepphus columba*)	35	0.39
Bonaparte's Gull (*Larus philadelphia*)	32	0.36
Common Murre (*Uria aalge*)	26	0.29
Common Merganser (*Mergus merganser*)	26	0.29
Common Loon (*Gavia immer*)	22	0.25
Mew Gull (*Larus canus*)	20	0.22
White Winged Scoter (*Melanitta fusca*)	13	0.15
Scoter Species (*Melanitta spp.*)	11	0.12
Unidentified Loon Species (*Gavia spp.*)	9	0.10
Red Necked Phalarope (*Phalaropus lobatus*)	9	0.10
Pacific Loon (*Gavia pacifica*)	6	0.07
Merganser Species (*Mergus spp.*)	6	0.07
Goldeneye Species (*Bucephala spp.*)	6	0.07
Unidentified Duck Species	5	0.06
Harlequin Duck (*Histrionicus histrionicus*)	1	0.01
Arctic Tern (*Sterna paradisaea*)	1	0.01
TOTAL	8890	

Table 3. Inventory of species present in Port Snettisham that are known to be preyed upon by MAMU elsewhere.

Prey Type	Species	Sampling Method
Fish	*Mallotus villosus*	Beach Seine, Dip Net, Plankton Tow
	Oncorhynchus gorbuscha	Beach Seine, Dip Net
	Oncorhynchus keta	Beach Seine
	Oncorhynchus tshawytscha	Beach Seine
	Oncorhynchus kisutch	Beach Seine
	Oncorhynchus nerka	Beach Seine
	Ammodytes hexapterus	Beach Seine
	Salvelinus malma malma	Beach Seine
	Theragra chalcogramma	Beach Seine
	Trichodon trichodon	Beach Seine
Plankton	Euphausid sp.	Plankton Tow
	Chaetognatha sp.	Plankton Tow
	Amphipod sp.	Plankton Tow
	Mycid sp.	Beach Seine

Table 4. Euphausid and Amphipod counts for T6-9 and T14-16. Each number represents the sum of the four sample stations along each transect section.

	Euphausids		Amphipods	
Date	T6-T9	T14-T16	T6-T9	T14-T16
1-Jul	35	15	26	99
9-Jul		285		119
14-Jul	75		148	
16-Jul		104		325

Table 5. Bivariate Spearman's correlation (r_s) of continuous dependent and independent variables. No adjustments were made to significance values for multiple comparisons.

	MAMU Abundance	MAMU Group Count	Prey Target Count	Prey Target Sum	Tidal Slick	Distance to Creek	Distance to Flyways	Distance to Shoreline
MAMU Group Count	.898(**)							
Prey Target Count	.140(**)	.155(**)						
Prey Target Sum	.141(**)	.156(**)	.979(**)					
Tidal Slick	.018	.048	-.008	-.012				
Distance to Creek	-.118(**)	-.190(**)	-.096(*)	-.095(*)	.019			
Distance to Flyways	-.222(**)	-.259(**)	-.216(**)	-.197(**)	-.182(**)	.217(**)		
Distance to Shoreline	-.178(**)	-.292(**)	-.178(**)	-.179(**)	.013	.655(**)	.237(**)	
Depth	-.255(**)	-.275(**)	-.061	-.053	-.028	.249(**)	.285(**)	.150(**)

*Significant at the 0.05 level (2-sided)

**Significant at the 0.01 level (2-sided)

Table 6. Mann-Whitney U test results for the 100 m bin scale using MAMU presence-absence as the grouping variable.

	U	Z adjusted	p-value
Prey Target Count	15565.5	-2.705	0.007
Prey Target Size	15501.0	-2.791	0.005
Tidal Slick	16419.0	-1.780	0.075
Creek	14393.0	3.254	0.001
Flyways	11814.0	5.683	<0.001
Shoreline	12365.0	5.164	<0.001
Depth (m)	12246.0	5.276	<0.001

Table 7. Bivariate Spearman's correlation (r_s) matrix for the T6-T9 CART analysis

	MAMU Group Count/km	MAMU Abundance/km	Tidal Slick/km	Prey Target Count/km
MAMU Abundance/km	0.891(**)			
Tidal Slick/km	0.290	0.295		
Prey Target Count/km	0.297	0.181	-0.147	
Prey Target Sum/km	0.411	0.349	0.136	0.600(**)

*Significant at the 0.05 level (2-sided)

**Significant at the 0.01 level (2-sided)

Table 8. Patch length and crowding values from the Ripley's K analysis.

		Patch Length (km)			Crowding (# of MAMU)		
Transect	N	Mean	Standard Deviation	Range	Mean	Standard Deviation	Range
T1-T11	7	3.96	2.78	0.90-9.09	30.56	16.1	11.49-50.09
T12-T16	7	1.84	1.85	0.30-5.50	28.42	26.42	2.17-77.30
T6 - T9	21	1.95	1.39	0.50-5.10	18.1	14.4	2.53-48.46

Table 9. Statistical tests (Mann-Whitney for 2 groups, Kruskal-Wallis for 3 groups) for all four parameters for aggregation, for all six independent variables. Results in bold are significant at the 0.05 level.

Parameter	Minimum Scale of Aggregation	Patch Length	Crowding	Spatial Range of Aggregation
Range	0.1 to 4.1 km	0.1 to 4.8 km	0.86 to 88.80	0-13.2 out of 14.4 km
Mean	0.92 km	1.58 km	15.08	4.63 km
SD	1.27 km	1.58 km	20.96	4.52 km
MAMU abundance	U=19.0, z=-1.730, p=0.084	U=21.0, z=-1.445, p=0.148	U=33.0, z=-0.289, p=0.773	U=31.5, z=-0.795, p=0.427
MAMU group count	U=29.5, z=-0.281, p=0.779	U=31.5, z=-0.434, p=0.665	U=28.0, z=-0.770, p=0.441	U=38.5, z=-0.177, p=0.860
Mean MAMU group size	**U=11.5, z=-2.493, p=0.013**	**U=14.5, z=-2.298, p=0.022**	U=35.0, z=-0.096, p=0.923	U=35.5, z=-0.442, p=0.659
Prey target count	U=25.5, z=-0.730, p=0.465	U=25.5, z=-1.012, p=0.213	U=31.0, z=-0.481, p=0.630	U=37.0, z=-0.309, p=0.757

APPENDIX E

Prey target sum	H=1.713 DF=2 P=0.425	H=2.061 DF=2 P=0.357	H=0.493 DF=2 P=0.781	**H=9.199, DF=2, p=0.010**
Breeding Periods	H=1.713 DF=2 P=0.425	H=2.061 DF=2 P=0.357	H=0.316 DF=2 P=0.854	H=2.125 DF=2 P=0.346

Figures:

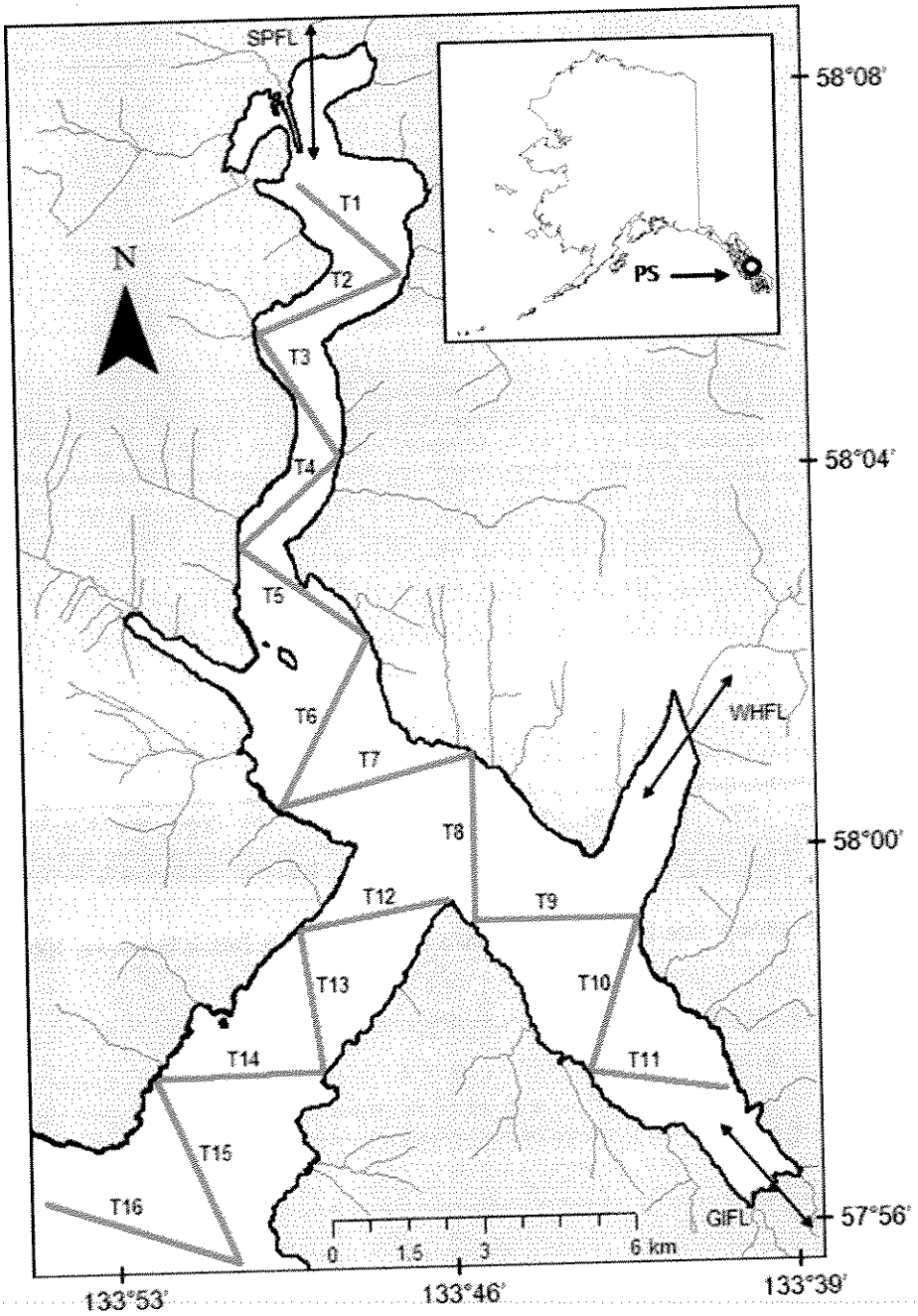

Figure 1. Transects used to survey the at-sea distribution of MAMU in Port Snettisham, AK. Dark grey lines indicate transect route. Double-headed arrows indicate major flyways (GIFL = Gilbert Bay flyway, WHFL = Whiting River flyway, SPFL = Speel River flyway) for murrelets inland to nesting habitat. Numbers on the edge of the figure represent latitude and longitude.

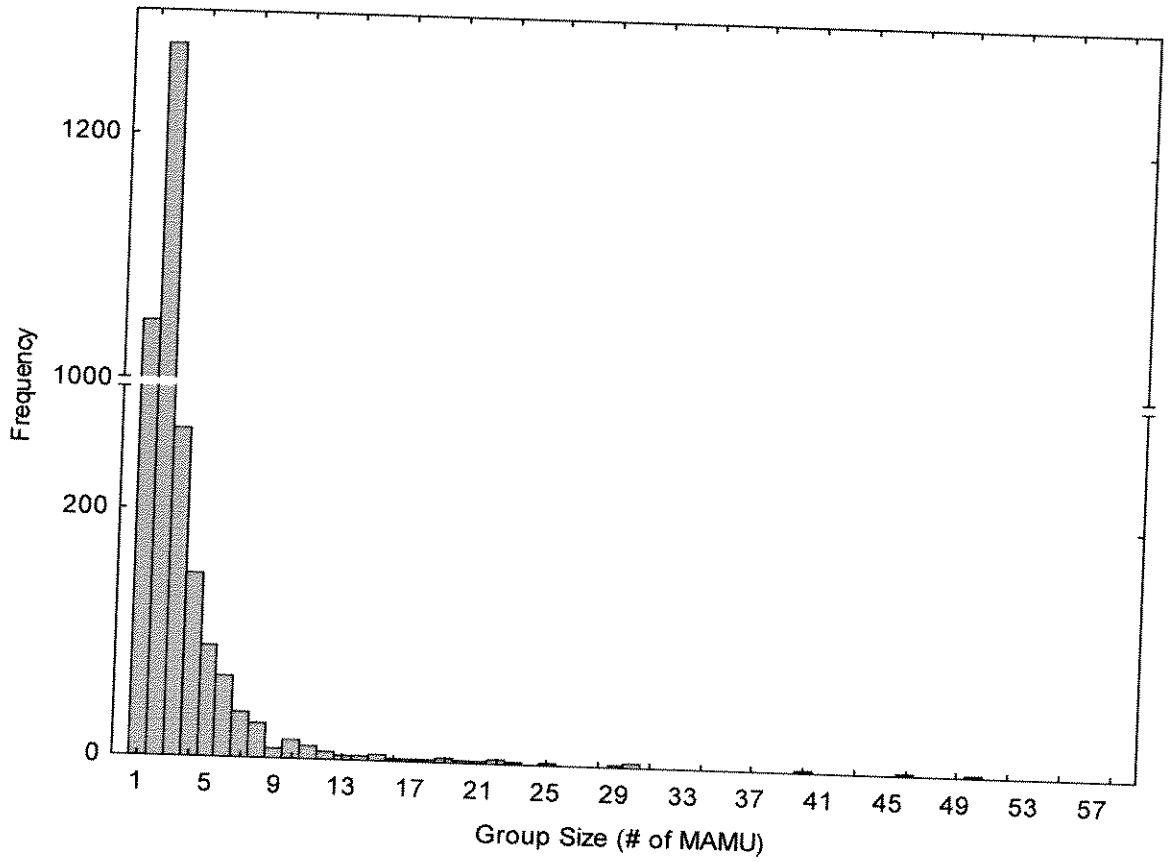

Figure 2. Histogram of MAMU group size from day transects (note the scale break between 300-1000).

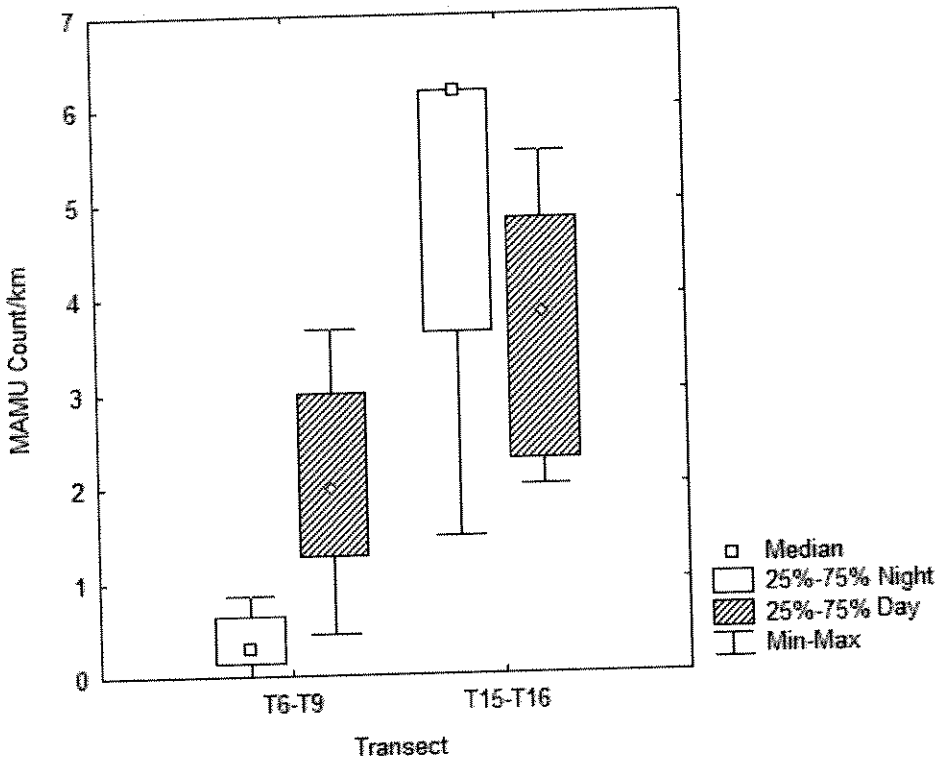

Figure 3. Night (open) and day (hatched) MAMU abundance/km for T6-T9 and T15-T16.

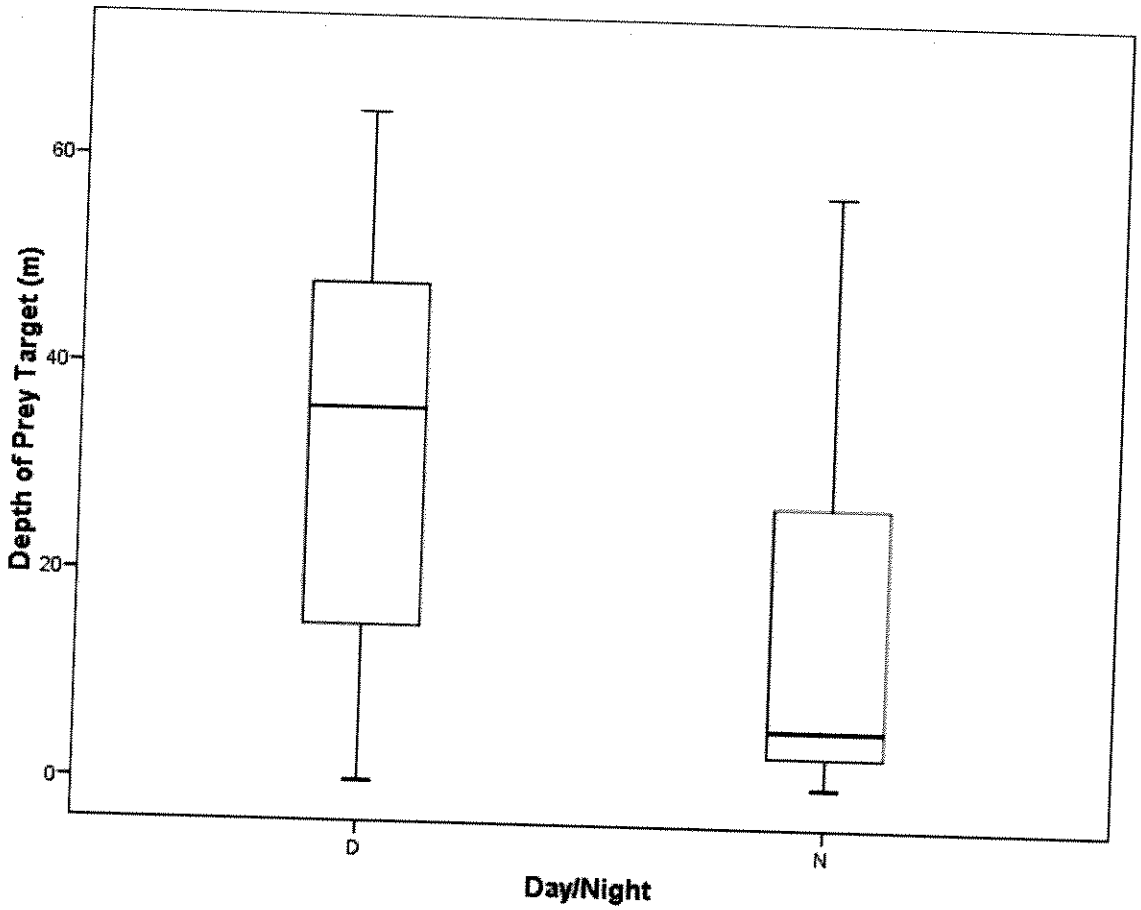

Figure 4. Comparison of depth of prey targets recorded on the echo sounder between night (N = 50) and day (N = 193).

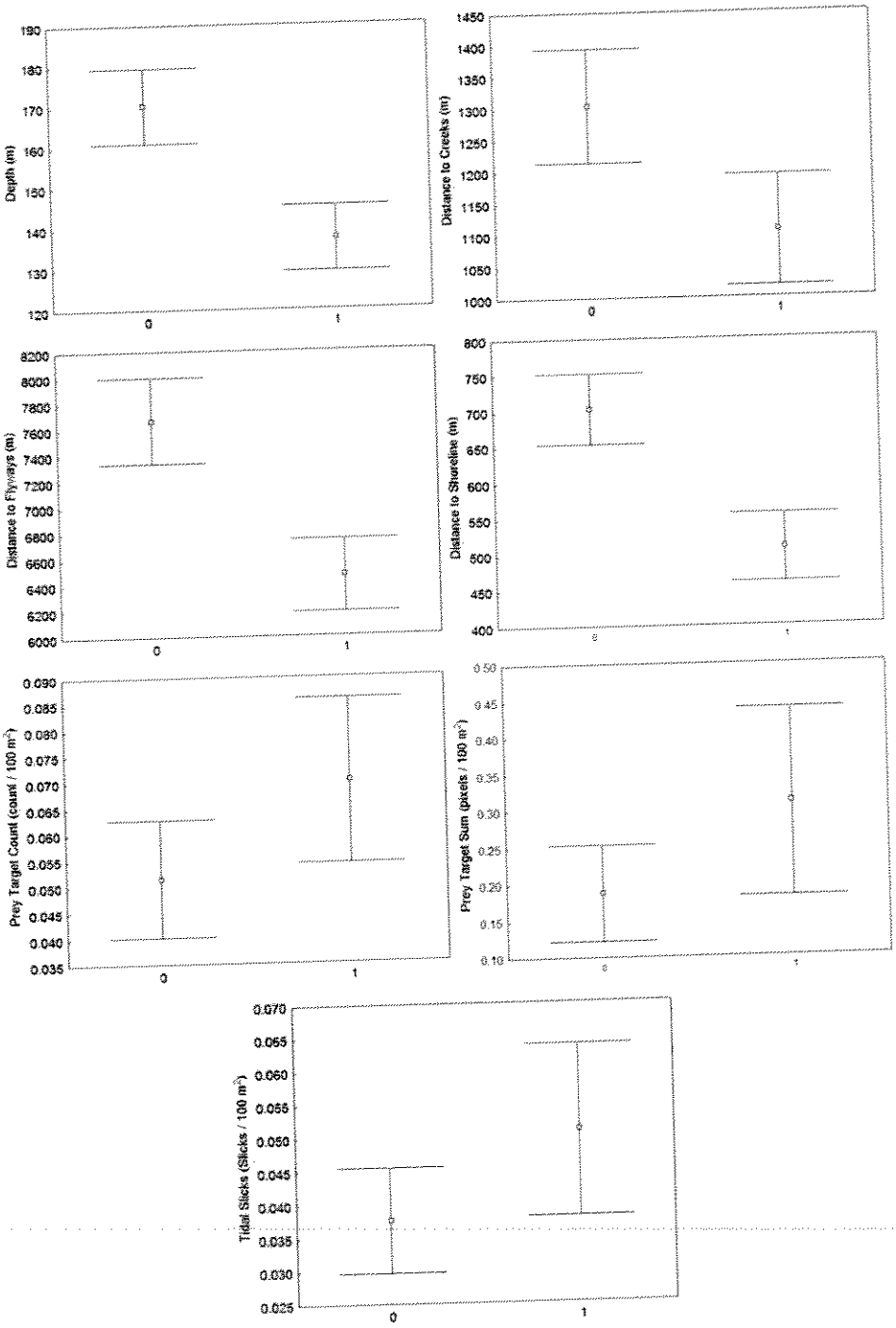

Figure 5. Mean plots for continuous habitat variables grouped by MAMU presence-absence (1-0, respectively). Squares mark mean values and whiskers represent 95% confidence intervals.

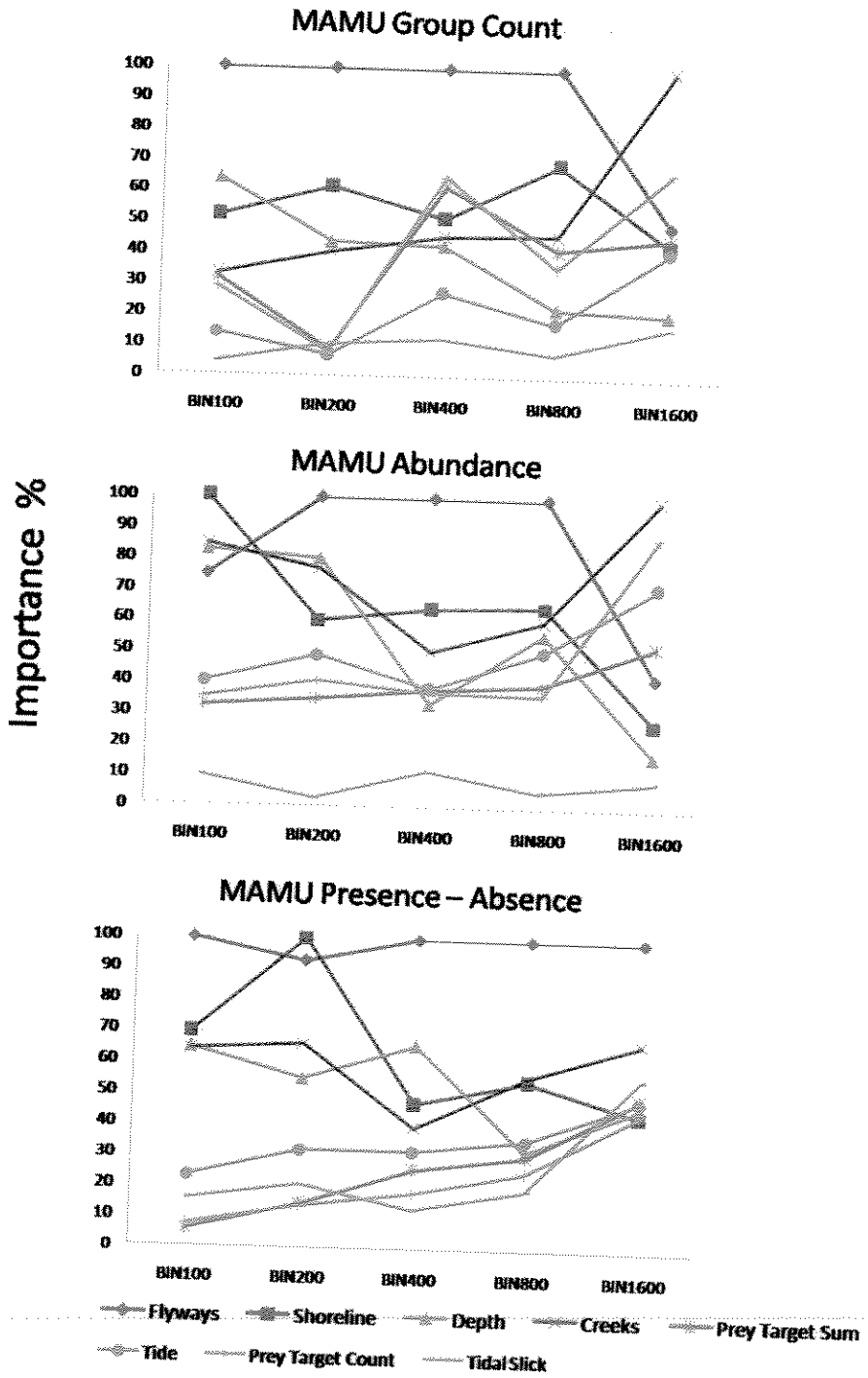

Figure 6. Normalized importance values (%) for each dependent variable based on ten trees grown for each bin size.

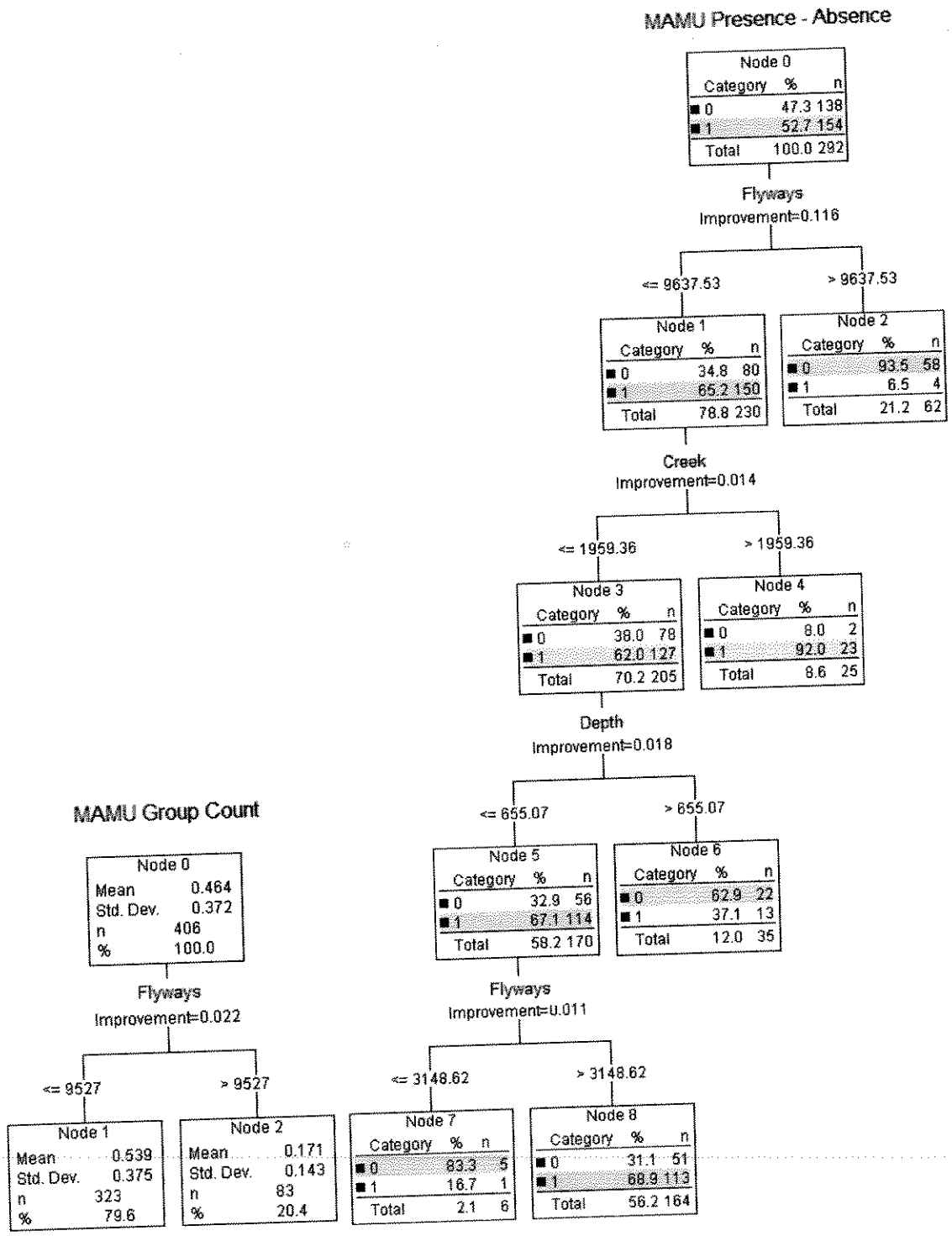

Figure 7. Regression tree for MAMU group count and MAMU presence-absence at the 100 m scale based on seven independent variables: prey target count, prey target sum, tidal slick, distance to creeks, distance to shore, distance to flyway, and depth.

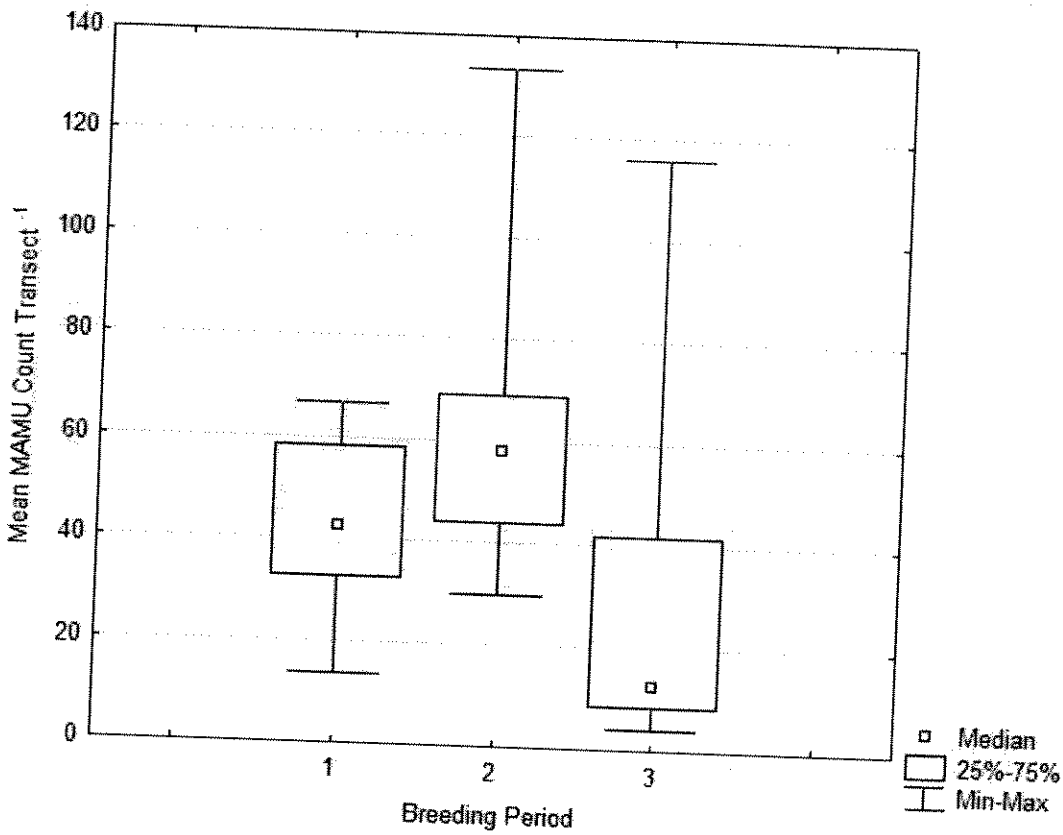

Figure 8. Boxplot of mean MAMU count *versus* breeding period. Breeding season was broken into the three breeding periods: (1) Nesting initiation and incubation (25-May to 19-June), (2) Incubation and chick rearing (19-June to 12-July), and (3) chick rearing/post breeding (begins 13-July).

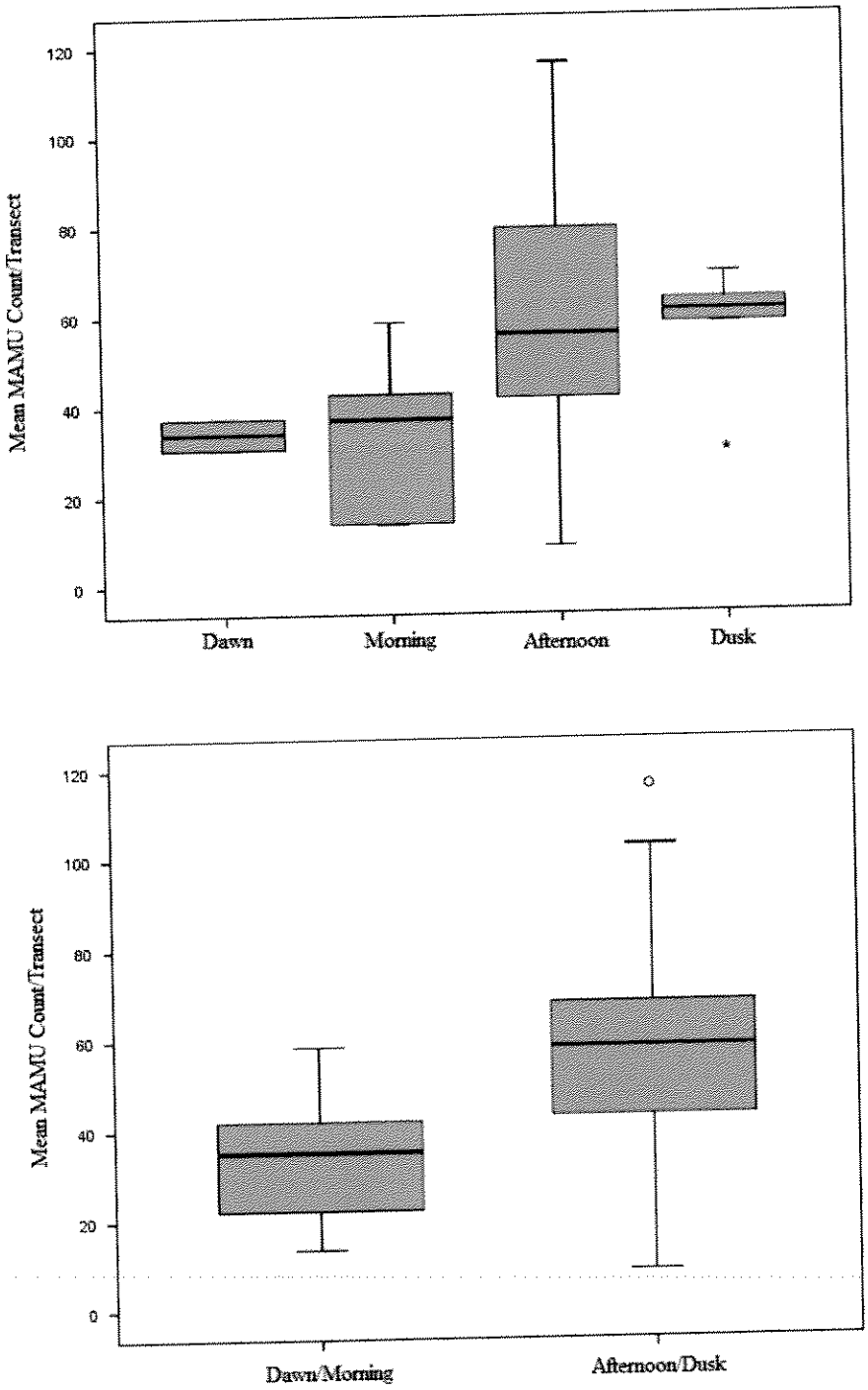

Figure 9. Mean MAMU counts for T6-T9 broken into time periods.

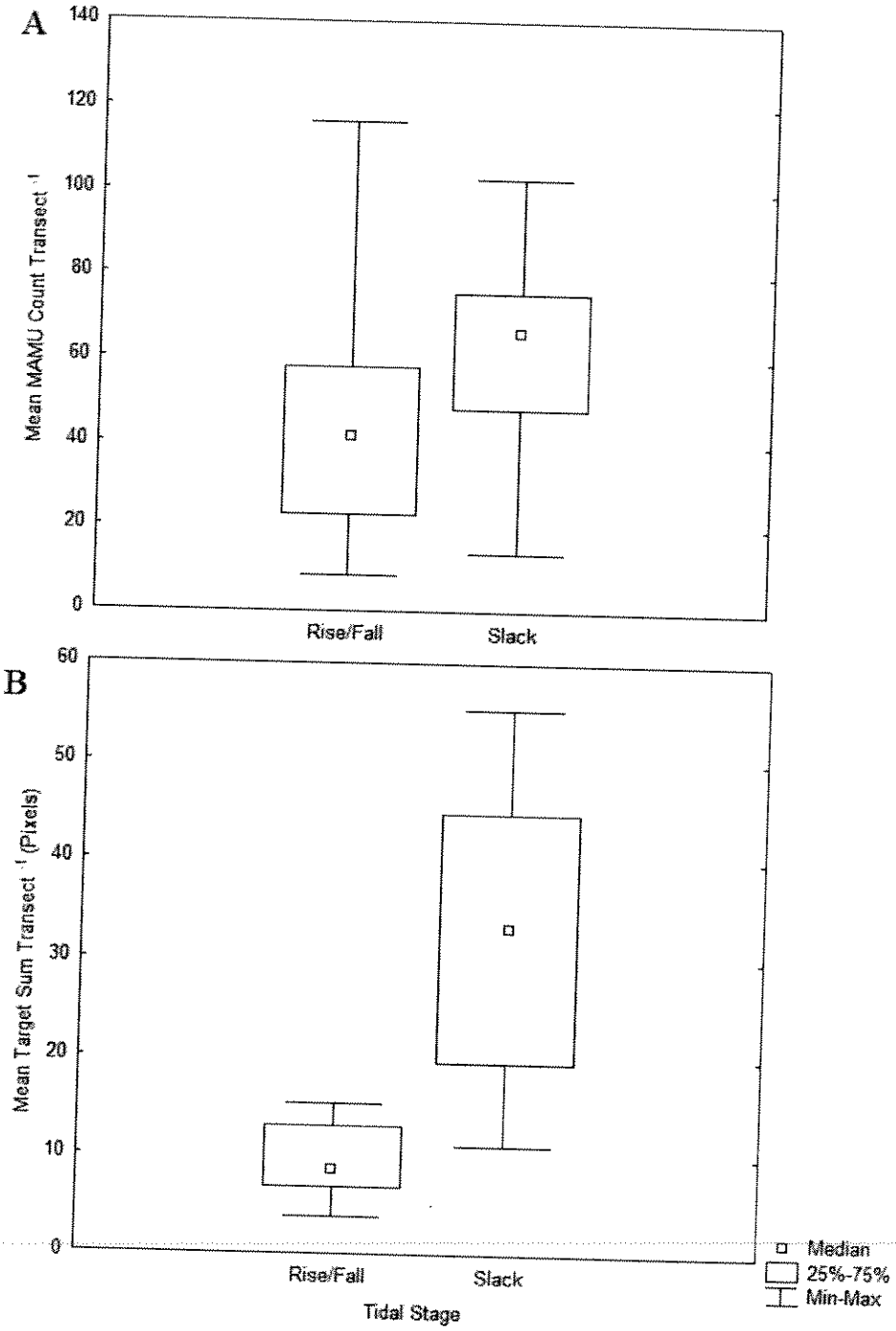

Figure 10. Boxplots of both MAMU abundance and mean target sum per transect versus tidal stage (for T6-T9). Slack tide represents the period one h before and after high or low tide and rise/fall represents all other tide periods.

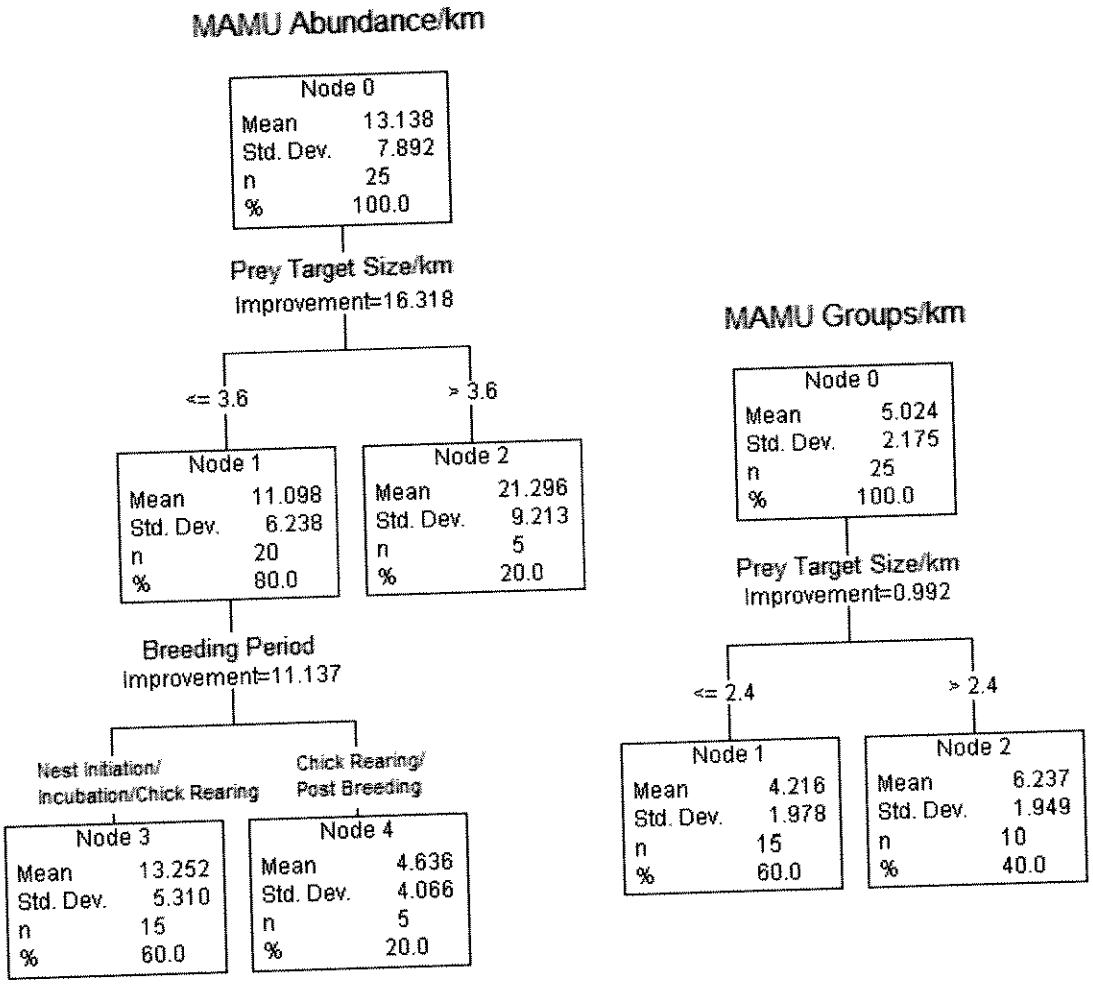

Figure 11. Regression trees for MAMU abundance and MAMU group count for the T6-T9 region (14.2 km, N=25) based on six independent variables: prey target size, prey target count, breeding period, tidal slicks, tidal stage, and time of day.

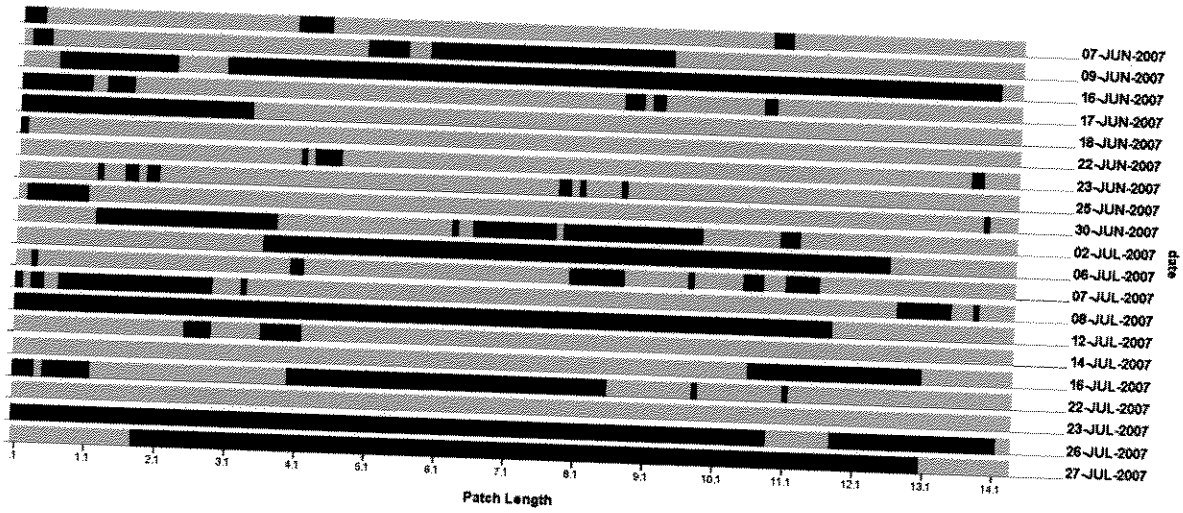

Figure 12. Plot of significant aggregations between MAMU and prey targets for each study day. Black bars show range of significant aggregation and grey bars show ranges where no significant aggregation exists, based on 99% confidence interval from Monte-Carlo simulation.

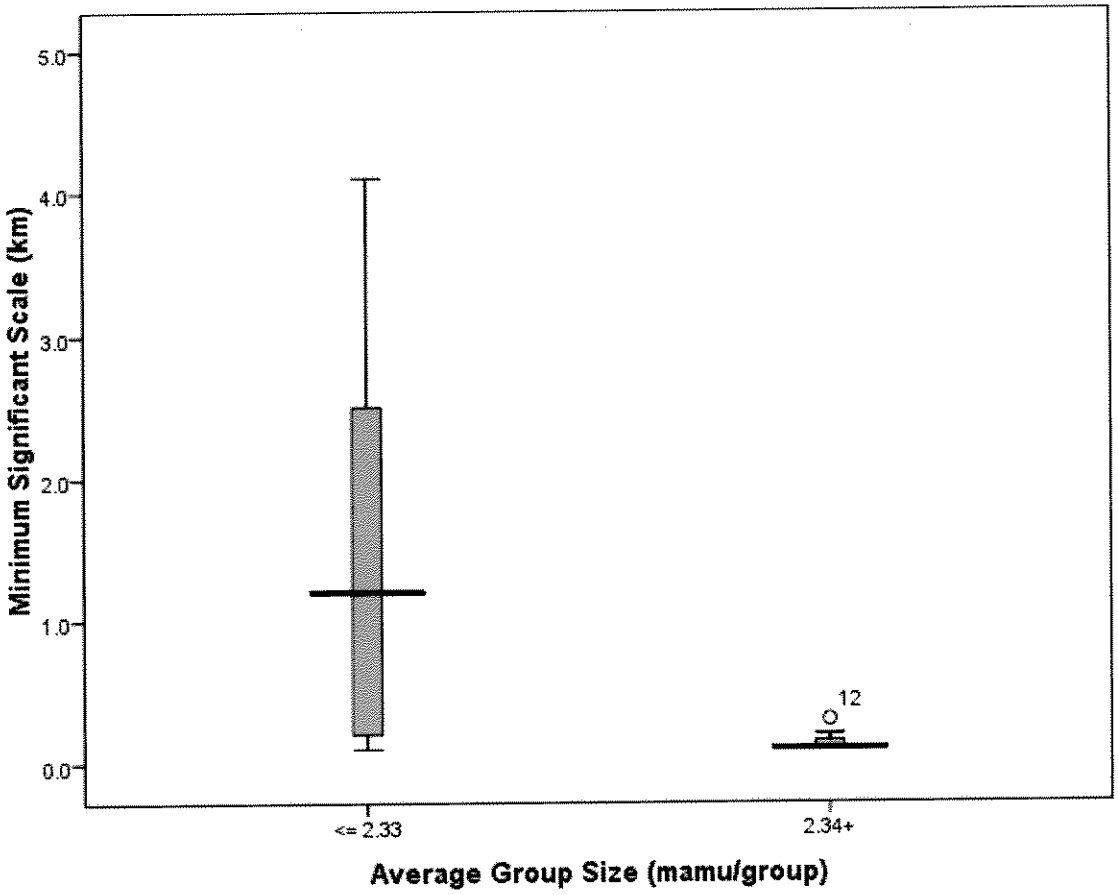

Figure 13. Boxplot of minimum significant scale grouped by mean MAMU group size.

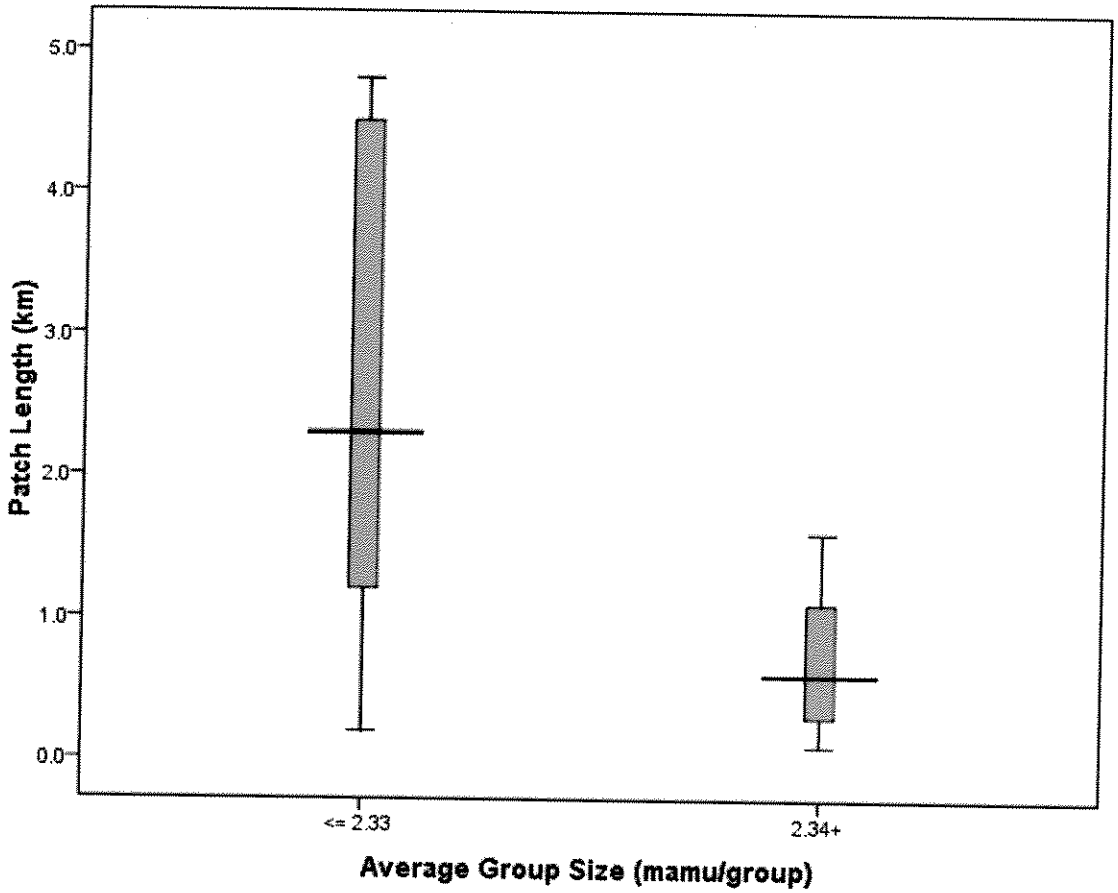

Figure 14. Boxplot of patch length (km) grouped by mean MAMU group size.

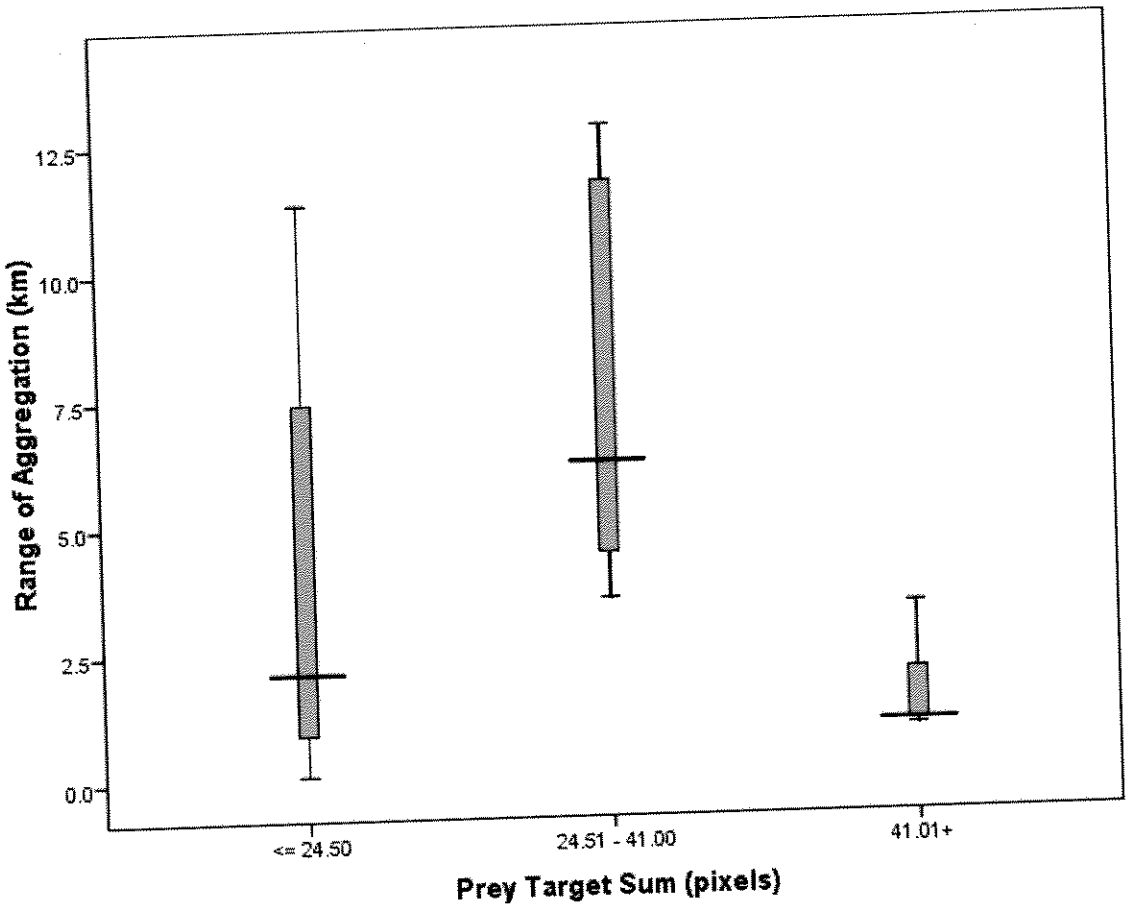

Figure 15. Boxplot of spatial range of aggregation grouped by prey target sum.

APPENDIX F

M.Z. Peery
L.A. Hall

Title: Adaptive Genetic Diversity of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska compared to other population centers within the species' range

Principle Investigator: Zachariah Peery, Moss Landing Marine Laboratories, 8272 Moss Landing Rd., Moss Landing, CA 95039,(831) 771-4139, zpeery@nature.berkeley.edu

Cooperator: Laurie A. Hall (graduate student under supervision of the PI)

Funding request: $66,500.00

Match Provided: $67,456.00 (100%)

Justification/Need:

This study will provide information important to the conservation and management of the Marbled Murrelet (*Brachyramphus marmoratus*), a species identified as imperiled and in need of conservation in Alaska's Comprehensive Wildlife Conservation Strategy (ACWCS, http://www.sf.adfg.state.ak.us/statewide/ngplan/NG_outline.cfm; Appendix 4, page 211). This particular project provides information on genetic distinctiveness of the species (Issue 5 and Global Conservation and Management Objective/Issue 1; ACWCS Appendix 4, page 214, 215), including functional evolutionary significant units (ESUs) and Management Units (MUs) which will bear on future listing decisions for this species under the Endangered Species Act. Blood samples are already in hand, and the laboratory techniques have been developed. This request is to fund the labor and fixed costs associated with the processing of the samples and analysis of the resultant genetic data.

Project Duration:

The project is for one fiscal year, commencing July 1, 2008, and ending June 30, 2009.

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Project Location:

Samples have already been collected from collaborators in Alaska and from 5 other locations throughout the Marbled Murrelet's North American range. The work that is being funded will be conducted at Moss Landing Marine Lab (in California).

Project Summary:

A recent range-wide genetic analysis of Marbled Murrelets detected little population genetic structure from central Alaska to northern California using presumed neutral genetic markers, such as mitochondrial DNA, nuclear introns, and microsatellites (Friesen et al. 2005, Piatt et al. 2007). Here, we propose to characterize adaptive genetic variation in Marbled Murrelet populations from Alaska to California using the major histocompatibility complex (MHC). MHC markers are functional genes involved in immune response that are thought to be influenced by selection pressures and may diverge rapidly even for large populations. We hypothesize that Marbled Murrelets will have high genetic diversity within the MHC region examined and that genetic differentiation among murrelet populations may occur at a finer scale than detected previously with neutral markers.

Background Information:

Friesen et al. (2005) and Piatt et al. (2007) recently completed a range-wide genetic analysis for Marbled Murrelets that revealed significant genetic differentiation at the peripheral regions of the species range (i.e. the Aleutian Islands and central California), but detected little genetic structure in the center of the range (i.e., central Alaska to northern California). However, these studies used presumed neutral genetic markers (mitochondrial DNA, nuclear introns and microsatellites), which are generally not influenced by natural selection. For neutral loci such as these, the rate and magnitude of among-population genetic differentiation is due, in part, to the influence of random genetic drift, where divergence is relatively slow for large populations. Thus, the lack of genetic differentiation detected among murrelet populations from northern California to central Alaska could be due to the fact that these populations still number in the tens of thousands and are diverging slowly at neutral markers. In contrast, adaptive genetic markers experiencing strong differential selection among populations can diverge relatively quickly, even for large populations. Thus characterizing variation using adaptive genes may provide greater resolution of population genetic structure than neutral markers alone.

Here, we propose to characterize the genetic population structure of Marbled Murrelets using nucleotide sequences from a region of the MHC. The functional genes of the major histocompatibility complex (MHC) are useful adaptive genetic markers that code for transmembrane glycoproteins, which are involved in immune response. Differences among populations observed at MHC makers may be caused by differences in positive selection pressures acting on populations or differing demographic histories among populations (Hedrick 1999). Typically, the level of variation at MHC markers among populations is high for seabirds and members of the order Charadriiformes (Walsh and Friesen 2003, Kikkawa et al. 2005, Ekblom et al. 2007). For example, Ekblom et al. (2007) detected greater genetic population structure using MHC than with microsatellites

for Great Snipes (*Gallinago media*). Thus, assessing variation using adaptive genetic markers, such as the MHC, may yield a finer-scale resolution of the genetic structure of murrelet populations than neutral genetic markers alone.

Considering adaptive genetic diversity is an important component of delineating Evolutionary Significant Units (ESU's) and Managements Units (MU's) as it is adaptive genetic variation that provides the basis for future evolutionary potential in the light of environmental change. Moreover, considering neutral and adaptive genetic diversity together can further improve management decisions, a strategy that has been used by fisheries biologists to define ESU's and MU's (Waples 1995) and genetic stock identifications for Pacific salmon (*O. tshawytscha, O. nerka, O. kisutch*; Miller et al. 2002) and Sonoran topminnows (*Poeciliopsis occidentalis*; Hedrick et al. 2001).

Objectives:

1. Characterize adaptive genetic variation in Marbled Murrelet populations from Alaska to California on the basis of genes within the Major Histocompatibility Complex (MHC).
2. Compare the genetic population structure of Marbled Murrelets using neutral versus adaptive genetic markers.
3. Consider neutral and genetic adaptive diversity in combination for the purpose of recommending Evolutionarily Significant Units (ESUs) and Management Units (MUs) for Marbled Murrelets.

Expected Results or Benefits:

Maintenance of genetic diversity in populations is a key component of any conservation strategy. Conservation laws such as the Endangered Species Act (ESA), and the National Forest Management Act (NFMA) are oriented towards the conservation of "distinct population segments", or "Evolutionarily Significant Units (ESUs). In order to manage and conserve ESUs, they must first be identified. We expect to provide an ecologically meaningful, and legally defensible, description of ESUs for marbled Murrelets. If it turns out that Marbled Murrelets in Alaska are genetically distinct (i.e., unique ESU), the ESA must be applied at that level. If they are not distinct, the relative abundance of Marbled Murrelets in Alaska will influence listing decisions for the species in other portions of their range (BC, and Lower 48 states).

Methods/Approach/Procedures:

Sampling

We will sequence a region of the MHC for 150 Marbled Murrelets from 6 geographically-defined populations - Southeast Alaska, Vancouver Island, Washington (San Juan de Fuca Strait), Oregon, northern California, and central California (approximately 25 samples per population). Blood samples from these individuals have been previously collected by MZP and collaborators and are in our possession at Moss Landing Marine Laboratories. DNA extractions have already been conducted using the DNeasy Tissue Extraction Kit (Qiagen, Valencia, CA), thus saving considerable time and expense.

Laboratory Methods

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Polymerase chain reaction (PCR) will be used to amplify a functional region of the MHC involved in antigen presentation (MHC class II exon 2 and exon 3) using previously published primers MHC GD 222 (5'-CCGGCAGCAGTACGTGCACTTCG-ACAGCGA-3') and MHC GD 719 (5'-GATGGGCTGCTGCAGGCTGGTGTGCT-3'; Walsh and Friesen 2003) modified with a GC-clamp. PCR products containing different alleles will be separated using a combination of denaturing gradient gel electrophoresis (DGGE) and constant denaturant gel electrophoresis (CDGE) as previously described (Ekblom et al. 2007). Unique alleles within PCR products will be visualized by ethidium bromide staining, excised from the gels, and soaked in 50ul water. After soaking, products will be re-amplified using PCR with MHC GD 222 and MHC GD 719 primers (Walsh and Friesen 2003) and then sent to a commercial laboratory for sequencing.

Sequence Editing and Analysis

Sequence chromatographs will be edited in Chromas (Technelysium Pty Ltd.), and aligned in ClustalX (Ramu et al. 2003). Differences of nonsynonymous (Dn) and synonymous (Ds) substitutions among sequences will be estimated using the methods of Nei and Gojobori (1986) and corrected using the Jukes and Cantor (1969) method. Gene diversity, nucleotide diversity, and allele frequencies will be calculated using Arlequin 2.0 (Schneider et al. 2000). Population genetic structure will be assessed using an analysis of molecular variance (AMOVA; Arlequin 2.0; Schneider et al. 2000).

Project Expenses (narrative form):

We are requesting $66,650 from the Alaska Department of Fish and Game for this project. These funds will be used to pay for LH's salary and benefits, laboratory supplies, and sequencing costs. We are requesting $25,000 in salary for LAH (10 months at $2,500/month) with 15% benefits ($3,750). We are requesting $10,000 for laboratory supplies such as reagents (e.g., *taq*, dNTPs) and plastics (e.g. PCR plates, microcentrifuge tubes, pipette tips), and $10,000 for DNA sequencing services. We are also requesting $5,000 to purchase a denaturing gradient gel electrophoresis rig required for the separation of PCR product. As we are currently working a large scale genetic project for Marbled Murrelets, we have the ability to provide significant matching funds for this project (totaling $64,456). Specifically, MZP's salary and benefits (3 months) for this project are already funded by the Pacific Lumber Company (totaling $36,400). LH's tuition ($3,000) will also be paid for by miscellaneous grants to LH. Moss Landing Marine Laboratories will provide all other necessary equipment, such as centrifuges, pipetters, thermal cyclers, gel boxes. We estimate that the value of these items for the proposed project is about $15,000 given that their total cost was about $100,000 and about 15% of their use will be devoted to this project. We will also be able to reduce the total overhead from 48% to 24% - thus providing an additional $13,056 in matching funds.

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