

## CONCLUSIONS

The three chapters of this dissertation examined Marbled Murrelet behavior and activity patterns in forest and marine ecosystems. Diving behavior was recorded from telemetered birds along the central Oregon Coast in 1995 and 1996 while inland survey data were collected in old-growth Douglas-fir forests of the Oregon Coast Range in 1994, 1996, and 1997. Along with improving our understanding of murrelet behavior in each ecosystem, these studies were conducted in order to improve our understanding of how behavior in forest systems may be related to conditions or behaviors in marine systems.

Through observations of telemetered birds, we determined that diving behavior differed between years while variables representing short-term sea conditions, location, and water depth had weaker and less consistent effects on diving performance. Diving performance of Marbled Murrelets in this study appeared to be affected by annual changes in environmental conditions and prey resources and did not consistently fit with predictions from optimal breathing models. This was evidenced by the lack of a significant relationship between dive time and pause time in 1995 but a positive significant relationship between dive time and both preceding and ensuing pause times in 1996. Therefore, it appeared that murrelet diving behavior was quite plastic and that individuals had the ability to vary their behavior as foraging conditions changed. Optimization models predicted behavior best when conditions appeared to be less optimal and birds were required to spend more time diving and foraging.

Similarly, activity patterns of Marbled Murrelets at inland forest sites appeared to be weakly related to short-term conditions such as weather at the stand and more strongly related to year. Each of the four daily activity metrics we monitored was highly variable within and among sites and years and we observed greater variability in activity levels than has been previously reported for this species. Activity metrics tended to be strongly correlated within a day within survey stations, but correlative relationships at temporal

and spatial scales greater than this were inconsistent and moderate at best. Based on our results, it appears murrelet activity at inland forest sites may be affected less by local, short-term conditions at forest stands and potentially more by foraging conditions at sea. For example, we observed highest levels of activity at inland forest sites when sea conditions appeared to be most favorable for forage fish and lowest levels of activity when sea conditions appeared least favorable. Therefore, it appears that activity at the nesting area may be affected by marine conditions; this is common in other alcids and colonial nesting seabirds.

Data discussed in Chapter 2 also were used to determine the feasibility of using inland surveys to seek temporal or spatial differences in daily detections; high levels of variability in daily detection counts have raised concern over using these data to do so. We determined how effectively various survey strategies estimated measures of daily mean and SD for detection counts of murrelets within a breeding season. It appears that, given the range of data we tested, it would be difficult to obtain reliable estimates of murrelet detections with sampling efforts up to 14 days/season. However, it does appear that detection data during a breeding season may be reliably estimated to within + 50% with similar or less effort. The power of survey strategies to detect annual declines in detections of 25% and 50% were very low and moderate, respectively, except when variability was quite low. Based on the results of our analyses in Chapters 2 and 3 we suggest that the use of Marbled Murrelet detection data for quantitative analyses be limited and considered at great length prior to initializing research or management efforts and that marine conditions always be considered when interpreting temporal trends in detection data.

Results from these analyses suggest that foraging conditions at sea likely play a major role in determining all aspects of this species behavioral ecology and therefore continued effort to understand this relationship is required. Inland survey data (i.e., daily detection or activity data), while quite useful for determining distribution and probable

nesting status, do not appear to lend themselves to rigorous quantitative analyses. Their use in such venues should be limited until a better understanding of the factors that affect variability in activity patterns is achieved.

Marbled Murrelets are unique among seabirds in their reliance upon forest and marine habitats during the breeding season. While this dissertation expanded upon our knowledge of their behavioral ecology in each system, there remains a great deal to be learned. Effective monitoring of this species and effective management of its habitat will require continued, focused research efforts such as these to complement the increasing number and diversity of marine and inland distribution surveys.

## BIBLIOGRAPHY

- Beier, P., and S.C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. *Wildlife Society Bulletin* 24:540-546.
- Bethge, P., S. Nicol, B.M. Culik, and R.P. Wilson. 1997. Diving behaviour and energetics in breeding little penguins. *Journal of Zoology, London*. 242: 483-502.
- Bost, C.A., and Y. LeMaho. 1993. Seabirds as bio-indicators of changing marine ecosystems: new perspectives. *Acta Oecologia* 14:463-470.
- Boyd, I.L., and J.P. Croxall. 1996. Dive durations in pinnepeds and seabirds. *Canadian Journal of Zoology* 74: 1696-1705.
- Burger, A.E. 1991. Maximum diving depths and underwater foraging in alcids and penguins. *Canadian Wildlife Service Occasional Paper, Ottawa, Canada* 68: 9-15.
- Burkett, E.E. 1995. Marbled Murrelet food habits and prey ecology. Pages 223-246 *In* C.J. Ralph, G.L. Hunt, M.G. Raphael, and J.F. Piatt, eds. *Ecology and Conservation of the Marbled Murrelet*. Gen. Tech. Rep. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA. 420 pp.
- Byrd, G. V., R.H. Day, and E.P. Knudston. 1983. Patterns of colony attendance and censusing of auklets at Buldir Island, Alaska. *Condor* 85: 274-280.
- Cairns, D.K. 1992. Diving behavior of Black Guillemots in Northeastern Hudson Bay. *Colonial Waterbirds* 15: 245-248.
- Cannell, B.L., and J.M. Cullen. 1998. The foraging behaviour of Little Penguins *Eudyptula minor* at different light levels. *Ibis* 140:467-471.
- Carter, H.R., and K.J. Kuletz. 1995. Mortality of Marbled Murrelets due to oil pollution in North America. Pages 261-270 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA. 420 pp.
- Carter, H.R., M.L.C. McAllister, M.E. Isleib. 1995. Mortality of Marbled Murrelets in gill nets in North America. Pages 271-284 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA. 420 pp.
- Chappell, M. A., V.H. Shoemaker, D.N. Janes, T.L. Bucher, and S.K. Maloney. 1993. Diving behavior during foraging in breeding Adelie Penguins. *Ecology* 74: 1204-

1215.

- Charnov, E.L. 1976. Optimal foraging: the marginal value theorem. *Theoretical Population Biology* 9: 129-136.
- Clowater, J.S., and A.E. Burger. 1994. The diving behaviour of Pigeon Guillemots (*Cepphus columba*) off southern Vancouver Island. *Canadian Journal of Zoology* 72: 863-872.
- Cohen, J. 1988. *Statistical power analyses for the behavioral sciences*. Second edition. Lawrence Erlbaum, Hillsdale, New Jersey, USA.
- Croll, D.A., A.J. Gaston, A.E. Burger, and D. Konnoff. 1992. Foraging behavior and physiological adaptation for diving in Thick-Billed Murres. *Ecology* 73: 344-356.
- de Leeuw, J.J. 1996. Diving costs as a component of daily energy budgets of aquatic birds and mammals: generalizing the inclusion of dive-recovery costs demonstrated in Tufted Ducks. *Canadian Journal of Zoology* 74: 2131-2142.
- Dewar, J.M. 1924. *The birds as a diver*. Witherby Press, London, UK.
- Duffy, D. C. 1990. Seabirds and the 1982 - 1984 El Nino-Southern Oscillation. Pages 395-415 *In* P. W. Glynn, eds. *Global ecological consequences of the 1982-83 El Nino-Southern Oscillation*. Elsevier, New York, USA.
- Evans, M., N. Hastings, B. Peacock. 1993. *Statistical distributions*. John Wiley and Sons. New York, New York, USA.
- Ewins, P. J. 1985. Colony attendance and censusing of Black Guillemots (*Cepphus grylle*) in Shetland. *Bird Study* 32: 176-185.
- Forest Ecosystem Management Assessment Team. 1993. *Forest Ecosystem Management: An ecological, economic, and social assesment*. USDA Forest Service Pacific Northwest Region, Portland, Oreegon, USA.
- Franklin, J.F., and C.T. Dyrness. 1988. *Natural vegetation of Oregon and Washington*. Oregon State University Press, Corvallis, Oregon, USA.
- Gaston, A. J., and I.L. Jones. 1998. *The Auks: Alcidae (Bird families of the world series)*. Oxford University Press, Oxford, England.
- Gaston, A. J., and D.N. Nettleship. 1982. Factors determining seasonal changes in attendance at colonies of the Thick-billed Murre (*Uria lomvia*). *Auk* 99: 468-473.
- Graybill, M.R., J. Hodder. 1985. Effects of the 1982-83 El Nino on reproduction of six

- species of seabirds in Oregon. Pages 205-210 in W.S. Wooster and D.L. Fluharty, eds. *El Nino north: Nino effects in the eastern subarctic Pacific Ocean*. University of Washington Press, Seattle, Washington, USA.
- Hair, J.F., Jr., R.E. Anderson, R.L. Tatham, W.C. Black. 1995. *Multivariate data analysis*. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Hamer, T. E., and S. K. Nelson. 1995. Nest tree and stand descriptions for Marbled Murrelets. Pages 49-56 in C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, CA: Pacific Southwest Research Station, Forest Service, USDA.
- Hatch, S. A., and M.A. Hatch. 1989. Attendance patterns of murrelets at breeding sites: implications for monitoring. *Journal of Wildlife Management* 53: 483-493.
- Hatfield, J.S., W.R. Gould IV, B.A. Hoover, M.R. Fuller, and E.L. Lindquist. 1996. Detecting trends in raptor counts: power and Type I error rates of various statistics. *Wildlife Society Bulletin* 24:505-515.
- Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. *Journal of Mammalogy* 78:514-524.
- Hayes, J.P., and R.J. Steidl. 1997. Statistical power analysis and amphibian population trends. *Conservation Biology* 11:273-275.
- Houston, A.I., and C. Carbone. 1992. The optimal allocation of time during the diving cycle. *Behavioral Ecology* 3: 255-265.
- Houston, A.I., and J.M. McNamara. 1985. A general theory of central place foraging for single prey-loaders. *Journal of Theoretical Biology* 28: 233-262.
- Hunt, G.L. 1995. Oceanographic processes and marine productivity in waters offshore of Marbled Murrelet breeding habitat. Pages 219-222 in C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, CA: Pacific Southwest Research Station, Forest Service, USDA; 420 pp.
- Jones, I. L., A.J. Gaston, and J.B. Falls. 1990. Factors affecting colony attendance by Ancient Murrelets (*Synthliboramphus antiquus*). *Canadian Journal of Zoology* 68: 433-441.
- Kaiser, G.W., H.J. Barclay, A.E. Burger, D. Kangasniemi, D.J. Lindsay, W.T. Munro, W.R. Pollard, R. Redhead, J. Rice, D. Seip. 1994. National recovery plan for the Marbled Murrelet. Rpt. no. 8. Ottawa, Canada: Recovery of nationally endangered wildlife committee, 36 pp.

- Kramer, D.L. 1988. The behavioral ecology of air breathing by aquatic animals. *Canadian Journal of Zoology* 66: 89-94.
- Lea, S.E.G., C. Daley, P.J.C. Boddington, and V. Morison. 1996. Diving patterns in Shags and Cormorants (*Phalacrocorax*): tests of an optimal breathing model. *Ibis* 138: 391-398.
- Manley, I., R. Shortt, and A. E. Burger. 1992. Marbled Murrelet activity patterns in the Carmanah Valley on the southwest coast of Vancouver Island. Pages 71-75 *in* K. Vermeer, B.W. Butler, and K.H. Morgan (eds.) *The ecology, status and conservation of marine and shoreline birds on the west coast of Vancouver Island*. Canadian Wildlife Service Occasional Paper, Ottawa, Canada.
- Marks, D.K., and N.L. Naslund. 1994. Sharp-shinned Hawk preys on a Marbled Murrelet nestling in old-growth forest. *Wilson Bulletin* 106:565-567.
- Monaghan, P., P. Walton, S. Wanless, J.D. Uttley, and M.D. Burns. 1994. Effects of prey abundance on the foraging behavior, diving efficiency and time allocation of breeding Guillemots (*Uria aalge*). *Ibis* 136: 214-222.
- Naslund, N.L., and B. P. O'Donnell. 1995. Daily patterns of Marbled Murrelet activity at inland sites. Pages 129-134 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA.
- National Buoy Data Center. 1997. Sea surface temperatures. <http://nimbo.wrh.noaa.gov/portland/marine.html>.
- Nelson, D. A. 1987. Factors influencing colony attendance by Pigeon Guillemots on Southeast Farallon Island, California. *Condor* 89: 340-348.
- Nelson, S. K., and T. E. Hamer. 1995. Nesting biology and behavior of the Marbled Murrelet. Pages 57-68 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). *Ecology and conservation of the Marbled Murrelet*. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA.
- Nelson, S.K., and R.W. Peck. 1995. Behavior of Marbled Murrelets at nine nest sites in Oregon. *Northwestern Naturalist* 76: 43-53.
- Noreen, E.W. 1989. *Computer intensive methods for testing hypotheses: An introduction*. J. Wiley, New York, New York, USA.

- O'Donnell, B.P., N.L. Naslund, and C.J. Ralph. 1995. Patterns of seasonal variation in activity of Marbled Murrelets in forested stands. Pages 117-128 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA.
- Orians, G.H., and N.E. Pearson. 1979. On the theory of central place foraging. Pages 155-177 *In* D.J. Horn, D.R. Mitchell, and G.R. Stairs, eds. Analysis of ecological systems. Ohio State Univ. Press, Columbus, Ohio, USA.
- Pacific Fisheries Environmental Group. 1997. Upwelling indices and sea surface temperatures. <http://www.pfeg.noaa.gov>.
- Perry, D.A. 1995. Status of forest habitat of the Marbled Murrelet. Pages 381-384 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA; 420 pp.
- Piatt, J. F., B.D. Roberts, and S.A. Hatch. 1990. Colony attendance and population monitoring of Least and Crested Auklets on St. Lawrence Islands, Alaska. *Condor* 92: 97-106.
- Quinlan, S.E., and J.H. Hughes. 1992. Techniques for capture and radio-tagging of Marbled Murrelets. *Proceedings of the Western Foundation of Vertebrate Zoology* 5: 117-121.
- Ralph, C. J., Jr. G. L. Hunt, M. G. Raphael, and J. F. Piatt. 1995a. Ecology and conservation of the Marbled Murrelet in North America: An overview. Pages 3-22 *in* C.J. Ralph, Jr., G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA; 420 pp.
- Ralph, C. J., Jr. G. L. Hunt, M. G. Raphael, and J. F. Piatt (eds.). 1995b. Ecology and conservation of the Marbled Murrelet. Gen. Tech. Rpt. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA.
- Ralph, C. J., S. K. Nelson, M. M. Shaughnessy, and S. M. Miller. 1994. Methods for surveying Marbled Murrelets in forests. Pacific Seabird Group Technical Paper #1: 27pp.
- Ramsey, F.L., and D.W. Schafer. 1997. The statistical sleuth: a course in methods of data analysis. Duxbury Press, Belmont California, USA.
- Ribic, C.A., and L.M. Ganio. 1996. Power analysis for beach surveys of marine debris.

- Marine Pollution Bulletin 32:554-557.
- Rodway, M. S., H.M. Regehr, and J-P. L. Savard. 1993. Activity levels of Marbled Murrelets in different inland habitats in the Queen Charlotte Islands, British Columbia. *Canadian Journal of Zoology* 71: 977-984.
- SAS Institute, Inc. 1985. SAS procedures guide for personal computers, version 6 edition. SAS Institute Inc., Cary, North Carolina, USA.
- Schreer, J.F., and K.M. Kovacs. 1997. Allometry of diving capacity in air-breathing vertebrates. *Canadian Journal of Zoology* 75: 339-358.
- Schwagmeyer, P.L., and D.W. Mock. 1997. How to minimize sample sizes while preserving statistical power. *Animal Behaviour* 54:470-474.
- Singer, S.W. D.L. Suddjian, and S.A. Singer. 1995. Fledging behavior, flight patterns, and forest characteristics at Marbled Murrelet tree nests in California. *Northwestern Naturalist* 76: 54-62.
- Sokal, R.R., and F.J. Rohlf. 1987. Introduction to biostatistics. Second edition. W.H. Freeman, New York, New York, USA.
- Steidl, R.J., J.P. Hayes, and E. Schaubert. 1997. Statistical power analysis in wildlife research. *Journal of Wildlife Management* 61:270-279.
- Stonehouse, B. 1967. Feeding behaviour and diving rhythms of some New Zealand shags, *Phalacrocoracidae*. *Ibis* 109: 600-605.
- Strachan, G., M. McAllister, and C. J. Ralph. 1995. Marbled Murrelet at-sea and foraging behavior. Pages 247-254 *In* C.J. Ralph, G.L. Hunt, M.G. Raphael, and J.F. Piatt, eds. Ecology and Conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA. 420 pp.
- Taylor, B.L., and T. Gerrodette. 1993. The uses of statistical power in conservation biology: the vaquita and Northern Spotted Owl. *Conservation Biology* 7:489-500.
- U.S. Department of Agriculture, and U.S. Department of the Interior. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl. U.S.D.A. Forest Service and U.S.D.I. Bureau of Land Management. Portland, Oregon, USA.
- U.S. Department of the Interior, Fish and Wildlife Service. 1992. Endangered and threatened wildlife and plants; determination of threatened status for the Washington, Oregon, and California population of the Marbled Murrelet. U.S. Federal Register

57:45328-45337.

- U.S. Department of the Interior , Fish and Wildlife Service. 1997. Recovery plan for the threatened Marbled Murrelet in Washington, Oregon, and California. Portland, Oregon, USA. 203 pp.
- Uttley, J.D., P. Walton, P. Monaghan, and G. Austin. 1994. The effects of food abundance on breeding performance and adult time budgets of guillemots (*Uria aalge*). *Ibis* 136: 205-213.
- Varoujean, D.H., and W.A. Williams. 1995. Abundance and distribution of Marbled Murrelets in Oregon and Washington based on aerial surveys. Pages 327-338 *In* C.J. Ralph, G.L. Hunt, M.G. Raphael, and J.F. Piatt, eds. Ecology and Conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152. Albany, California: Pacific Southwest Research Station, Forest Service, USDA.
- Wanless, S., T. Corfield, M.P. Harris, S.T. Buckland, and J.A. Morris. 1993. Diving behavior of the shag (*Phalacrocorax aristotelis*) in relation to water depth and prey size. *Journal of Zoology, London* 231: 11-25.
- Wanless, S., J.A. Morris, and M.P. Harris. 1988. Diving behaviour of guillemot (*Uria aalga*), puffin (*Fratercula arctica*) and razorbill (*Alca torda*) as shown by radio-telemetry. *Journal of Zoology, London* 216: 73-81.
- Watanuki, Y., A. Kato, and Y. Naito. 1996. Diving performance of male and female Japanese Cormorants. *Canadian Journal of Zoology* 74: 1098-1109.
- Weidinger, K. 1996. Patterns of colony attendance in the Cape Petrel (*Daption capense*) at Nelson Island, South Shetland Islands, Antarctica. *Ibis* 138: 243-249.
- Wilson, R.P. 1991. The behaviour of diving birds. *Proceedings of the International Ornithological Congress* 20:1853-1867.
- Wilson, U. W. 1991. Responses of three seabird species to El Nino events and other warm episodes on the Washington coast, 1979 - 1990. *Condor* 93: 853-858.
- Ydenberg, R.C. 1988. Foraging by diving birds. *Proceedings of the International Ornithological Congress* 19:1832-1841.
- Ydenberg, R.C., and C.W. Clark. 1989. Aerobiosis and anaerobiosis during diving by Western Grebes: An optimal foraging approach. *Journal of Theoretical Biology* 139: 437-449.
- Zielinski, W.J., and H.B. Stauffer. 1996. Monitoring *Martes* populations in California: Survey design and power analysis. *Ecological Applications* 6:1254-1267.