ASSOCIATION OF MARBLED MURRELETS *BRACHYRAMPHUS MARMORATUS* WITH FORAGING GRAY WHALES *ESCHRICHTIUS ROBUSTUS* ON THE SOUTHWEST COAST OF VANCOUVER ISLAND, BRITISH COLUMBIA

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SUMMARY

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Foraging in association with other species can be an important strategy that facilitates locating or capturing prey. We studied the association of Marbled Murrelets with foraging Gray Whales along a 105 km transect on the west coast of Vancouver Island, British Columbia, in June 2005. Gray Whales forage on benthic invertebrates by scooping up bottom sediments. Spatial association was analyzed across the extent of the transect and within a 50 m radius of surfacing whales. At both spatial scales, murrelets were more closely associated with Gray Whales than would be expected by chance. Murrelets were observed feeding in direct association with foraging whales, and qualitative observations from plankton tows indicated much more abundant zooplankton near surfacing whales. More research is needed to elucidate this relationship. Identifying facilitative relationships among marine organisms is important in understanding structure of food webs and adaptability to environmental change.

Key words: Facilitation, social foraging, interspecific associations, commensalism

INTRODUCTION

Pierotti (1988) classified five types of associations between marine birds and mammals: (A) birds occur with mammals but show no interaction; (B) birds are attracted to the same resource as mammals but not to the mammals themselves; (C) birds are actively drawn to mammals because they improve foraging opportunities; (D) birds scavenge byproducts (e.g. sloughed skin or food scraps); and (E) birds are actively preyed on by mammals. Type C interactions can be important in facilitating the location and capture of prey in the marine environment. Seabirds are known to form commensal associations with other seabirds, marine mammals and fish (Harrison 1979, Au & Pitman 1986). In many situations foraging by one individual can make prey more visible, accessible or concentrated, thus assisting foraging by other individuals. Commensal interactions can, therefore, increase intake during foraging, allowing more successful exploitation of ephemeral prey resources. Describing these relationships may improve our understanding of ecosystem function (Bruno *et al.* 2002).

Gray Whales *Eschrichtius robustus* frequently feed on benthic amphipods by gouging deep furrows in the ocean floor and straining the sediments through their baleen (Nerini 1984). As the whales rise to breathe, numerous invertebrates are brought to the surface in muddy plumes of sediment (Obst & Hunt 1990). In the Bering Sea, both surface-feeding and diving seabirds have been observed feeding in mud plumes generated by Gray Whales (Harrison 1979, Obst & Hunt 1990).

Gray Whales off the west coast of Vancouver Island feed primarily on the mysid crustacean *Holmesimysis sculpta* (Stelle 2002). Feeding whales are very visible and may serve as a foraging cue for Marbled Murrelets *Brachyramphus marmoratus* (Obst & Hunt 1990), which are common in this area (Burger *et al.* 2004), thus decreasing prey search time. Although the Marbled Murrelet's primary prey is fish, several studies have found that a significant proportion of its diet is made up of planktonic crustaceans. Sealy (1975) and Vermeer & Morgan (1992) found that crustaceans made up 27% and 28.7%, respectively, of murrelet diet, while Krasnow & Sanger (1982) and Sanger (1987) placed crustaceans as murrelets' second most important prey. Stable isotope studies have indicated that Marbled Murrelets in Barkley Sound, on the west coast of Vancouver Island, consume a diet consisting of about 85% fish, but also including invertebrate prey (Hobson 1990, Hobson *et al.* 1994). Carter (1984) reported an absence of planktonic crustaceans in murrelet summer diet, but these results do not preclude consumption of crustaceans by Barkley Sound murrelets in the summer, considering the murrelets' apparent prey-switching capability (Burkett 1995). Here we test whether at-sea distributions of Marbled Murrelets on the southwest coast of Vancouver Island are spatially associated with Gray Whales.

METHODS

Large-scale distribution patterns

We conducted surveys of whales and Marbled Murrelets from a 10.6 m passenger vessel along a 105 km transect from Bamfield to Port Renfrew on the west coast of Vancouver Island, British Columbia (Fig. 1). A single observer conducted surveys on 4 June, 6 June, 9 July and 10 July 2005, recording all birds and whales observed within 150 m from each side of the boat within 1 min intervals, at a height of 1.5–2 m above sea level using 7 × 50 binoculars for verification. Birds on the water or flying more than 250 m in front of the vessel, behind the vessel or following the vessel were not counted, following the methods of Burger *et al.* (2004). Boat speed remained relatively constant at 6 to 8 knots. Boat position, cloud condition and swell height were recorded every 30 min or as conditions changed. Sightings of whales and murrelets were recorded within 1 min intervals (i.e. transect segments). GPS positions were recorded whenever possible and used to verify the location of 1 min segments along transects. Maximum distance from the shoreline was 1.6 km, with a maximum depth of 45 m, determined from GPS data.

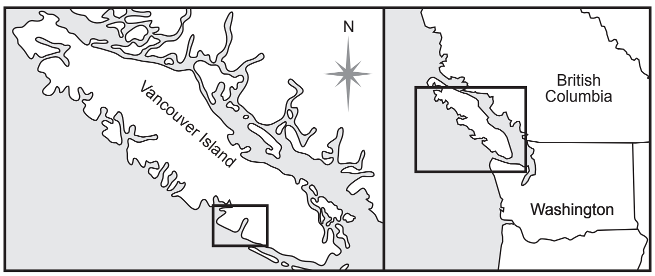

Fig. 1. Map of the study area from Bamfield to Port Renfrew on the west coast of Vancouver Island, British Columbia.

Distance to the nearest whale was calculated for each transect segment using the Pythagorean theorem (the middle of each 1 min segment was used to estimate each distance). As the distribution and abundance of whales were different for each survey, there were also differences in the number of transect segments available at a given distance from whales. To evaluate the hypothesis that Marbled Murrelets were positively associated with Gray Whales, we compared the observed distribution of murrelets relative to whales with the null hypothesis that murrelet occurrence was random with respect to the position of whales. Kolomogrov–Smirnov tests were used to evaluate whether murrelet distributions were statistically different from whale distributions.

Autocorrelation of seabird survey data can be a problem when analyzing trends, as the scale of analysis may not match the spatial structures being investigated, leading to pseudoreplication of data (Schneider 1990, van Franeker *et al*. 2002). To determine the correct spatial scale at which to analyze the data, we determined the autocorrelation of 10 min binned Marbled Murrelet observations within each transect. To determine the spatial scale at which

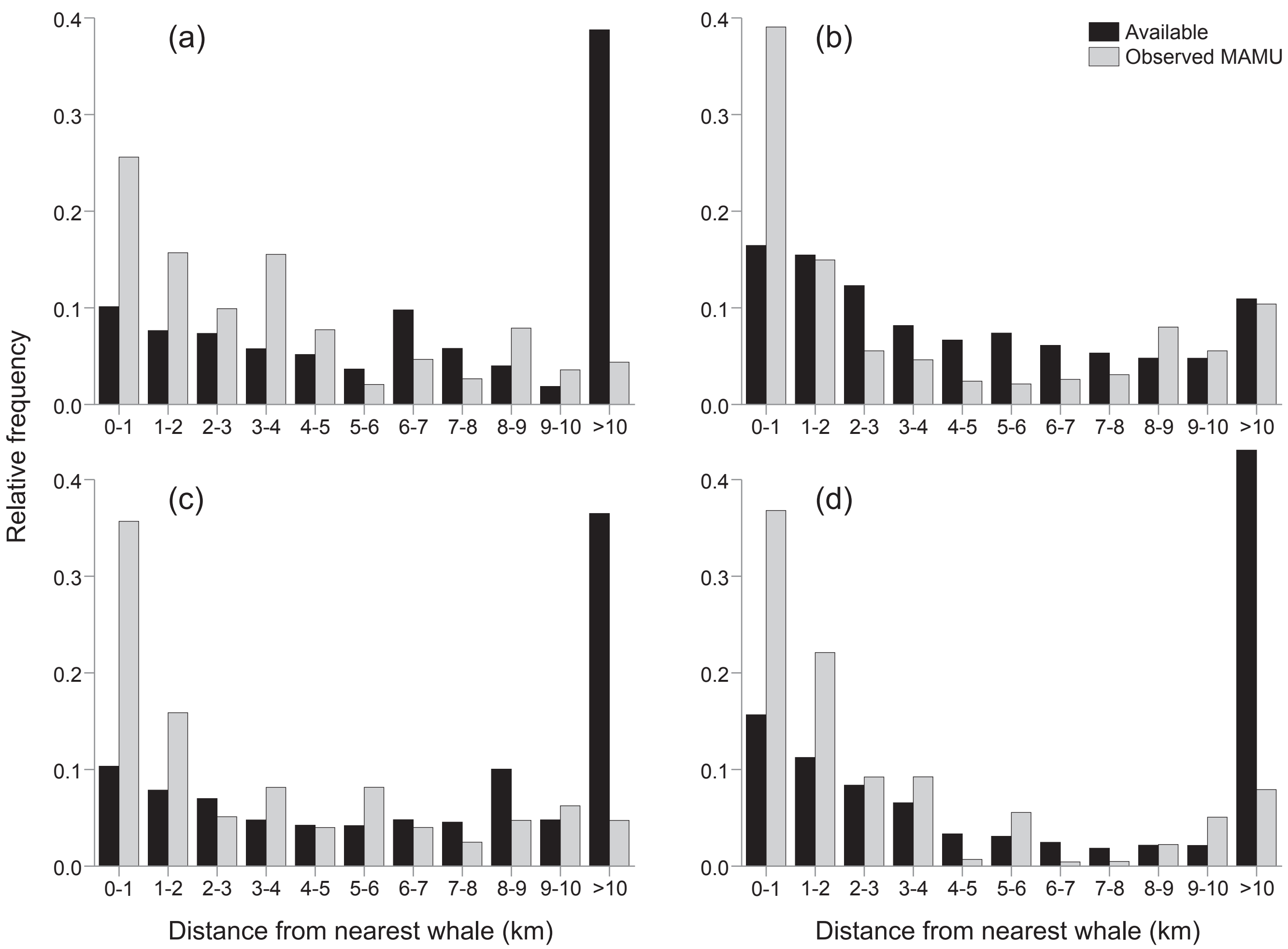

Fig. 2. Observed relative frequency distribution of Marbled Murrelets (gray bars, “MAMU”) and distance bins (by km) that were available for murrelets to use (sections) along transects (black bars) with respect to distance from Gray Whales on June 4 (a), June 6 (b), July 7 (c) and July 10, 2005 (d), indicating a significant association of Marbled Murrelets with whales.

the murrelet data are no longer autocorrelated, we analyzed the correlation coefficient within the data at increasing lags or distance between each 10 min observation period. The absence of autocorrelation was defined as I0, or the shortest lag for which the correlation is not significantly different from 0 (Sokal & Wartenberg 1983). We then used the maximum autocorrelation distance and re-binned the data for both Marbled Murrelets and whales to this spatial scale. Finally, we calculated the correlation between Marbled Murrelets and Gray Whales using these re-binned data.

Fine-scale association of murrelets with surfacing Gray Whales

When time allowed, transects were temporarily suspended to conduct finer-scale observations of Marbled Murrelets near whales. The still-water "footprint" of surfacing/diving whales was used as a reference point to estimate the distance of foraging murrelets within a 50 m radius of surfacing Gray Whales. On sighting, murrelets were instantaneously categorized by 10 m intervals (from 0 to 50 m in either direction) from the center of the footprint. To ensure consistency in detectability, birds further than 50 m from the whale footprint (i.e. outside a 100 m diameter area centered on the footprint) were not included. After each whale event, transects were resumed, taking note of the position, cloud conditions, swell height and time.

We calculated the available area in each 10 m ring around the center of the footprint, and divided the area of each region by the total area of the 50 m radius circle around the whale footprint, to determine the proportion of surface area available in each distance category. For each scan, we calculated the density of murrelets in each distance category, and divided by the cumulative density of murrelets to obtain the proportion (by density) of murrelets in each distance category for each scan. This allowed comparison of frequency distributions of observed murrelet density to the proportion of available surface area within the 50 m circle in which scans were conducted.

RESULTS

Large-scale distribution patterns

During the four surveys, 422 murrelets and 28 whales were observed within the transects. Comparison of cumulative frequency distributions indicated that Marbled Murrelets were positively

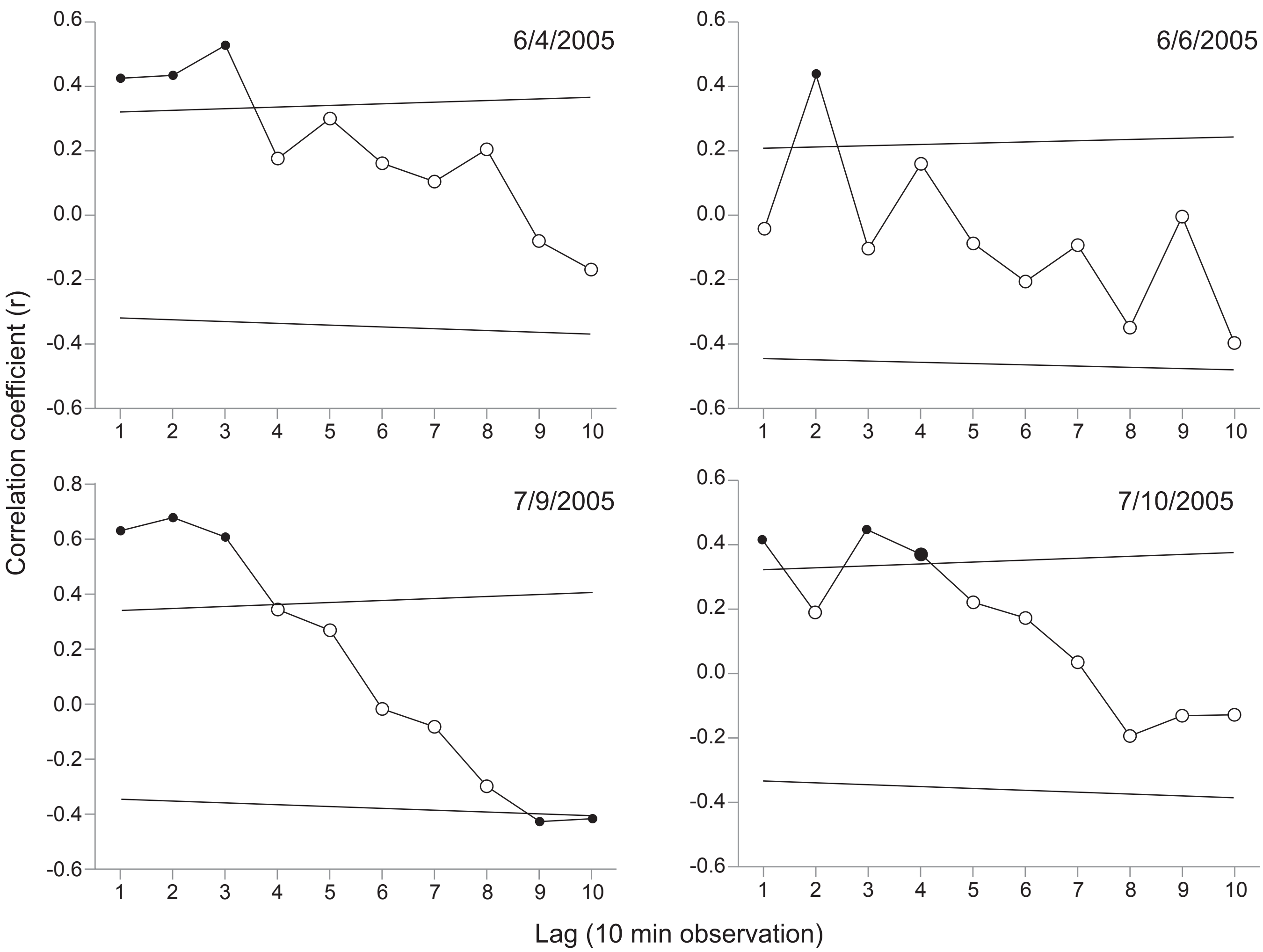

Fig. 3. Autocorrelation of Marbled Murrelets at lags of 1–10 10 min observations on four transects from Bamfield to Port Renfrew. Pearson correlation coefficients were tested against Pearson critical values ($\alpha = 0.05$). Marbled Murrelets show a patch scale between 0 and 1 and between 3 and 4 lags when tested against $P = 0.05$ (filled circles are significant). Data were subsequently re-binned to the maximum patch size (I0 = 3–4 lags) of 40 min.

associated with whales on 4 June (Kolomogrov–Smirnov (KS-Z = 1.49, P = 0.021), 9 July (KS-Z = 1.492, P = 0.021) and 10 July (KS-Z = 1.919; P = 0.001; Fig. 1). Although the analysis was not significant for 6 June (KS-Z = 0.640, P = 0.83), the majority of murrelets were still within 1 km of whale sightings (Fig. 2), and lack of significance for this test was likely due to a particularly even distribution of whales on this day, meaning that there were relatively few transect segments far away from whales.

Spatial autocorrelation in the 10 min observations of Marbled Murrelets ranged between 0 and 10 min (I0 = 0–1 lags) and between 30 and 40 min (I0 = 3–4 lags) in the four transects (Fig. 3). Using this information, we then re-binned the survey data into 40 min observations to prevent any autocorrelation. Using GPS data, we determined that the vessel traveled an average of 7.2 km in each 40 min observation period. The autocorrelation data also indicate the patch size of marbled murrelet aggregation, which ranged from 7.2 km to 28.8 km in diameter (Fig. 4). The correlation between Marbled Murrelets and Gray Whales was significantly positive (r = 0.37, P < 0.05; Fig. 4).

Fine-scale observations of murrelets and surfacing Gray Whales

Observations of murrelet distributions with respect to surfacing Gray Whales, averaged over 35 samples, indicated that murrelets were much closer to surfacing Gray Whales than would be expected if they were evenly distributed (Fig. 5). Murrelets were frequently seen moving towards surfacing whales and diving directly in the footprint. Having only five distance categories from the whales precluded informative statistical comparisons of these frequency distributions (Komologrov–Smirnov test). However, there is a clear trend of more birds closer to the footprint.

Anecdotal observations

Opportunistic plankton tows conducted from the *M/V Alta* near Seabird Rocks indicated the practical absence of zooplankton in tows conducted away from surfacing Gray Whales, although whales were known to forage in these locations on previous occasions. In contrast, tows directly through whale footprints shortly after the whale dove showed zooplankton presence, supporting our assumptions and existing reports of increased benthic invertebrate abundance around foraging Gray Whales (e.g. Obst & Hunt 1990).

DISCUSSION

Mud plumes generated by foraging Gray Whales are important for several species of seabirds in the Bering Sea (Harrison 1979, Obst & Hunt 1990). Our study indicates a strong association of Marbled Murrelets with Gray Whales at both broad and fine spatial scales along the southwest coast of Vancouver Island. Gray Whales were observed head downward, with their tails breaking the surface

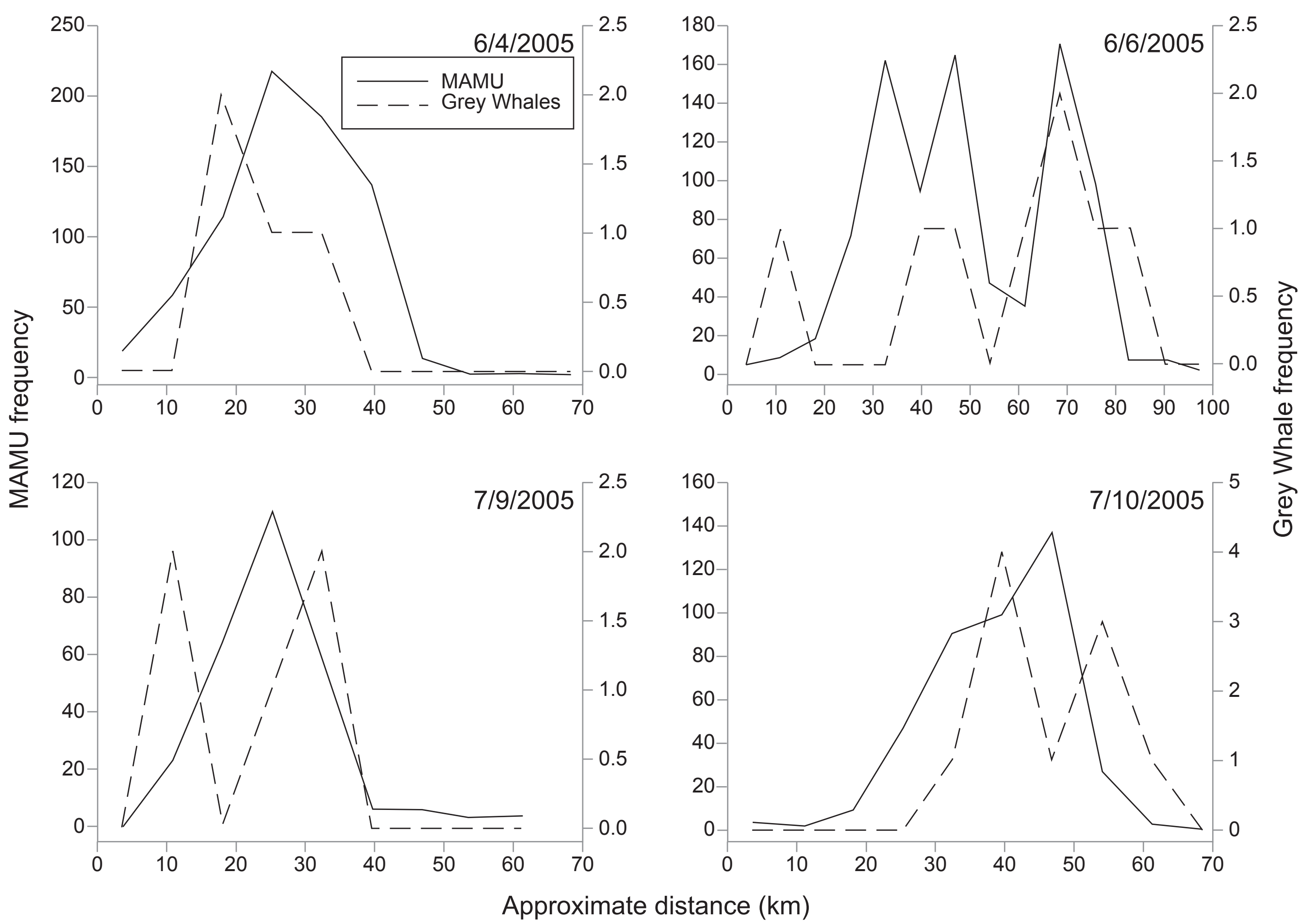

Fig. 4. The relationship between Marbled Murrelets (solid line) and Gray Whales (dashed line) for four transects from Bamfield to Port Renfrew. Because of the large difference in frequency, murrelets and whales are scaled on separate y-axes, allowing for a better representation of the relationship. Overall, murrelets and whales showed a significant positive correlation (r = 0.37, P < 0.05).

(Murison *et al.* 1984), and groups of murrelets were observed diving directly where the whales surfaced.

Large-scale associations between murrelets and whales may be due to a mutual association with productive areas (Type B), rather than a direct facilitation of foraging by whales (Type C) (Pierotti 1988). However, finer-scale observations indicated that murrelets were probably directly associated with surfacing Gray Whales. Other seabirds have been observed diving into the water directly behind or in front of Gray Whale feeding plumes (Obst & Hunt 1990); other alcids (Thick-billed Murre *Uria lomvia,* Dovekie *Alle alle)* have been shown to occur in greater densities with cetaceans in the Barents Sea (Mehlum *et al.*1998). Qualitative observations from plankton tows indicated zooplankton presence where whales had just surfaced.

Social foraging tactics are important for a wide variety of seabird species. Many seabird species, including a wide variety of species native to Vancouver Island (Porter & Sealy 1982), feed in mixed-species foraging flocks. In addition to concentrating prey, foraging flocks can provide an important visible indicator of prey resources (Obst & Hunt 1990), which are often ephemeral in the marine environment. Both mud plumes and the whales themselves could provide easily detectable foraging cues (Harrison 1979). Therefore, by associating with Gray Whales, murrelets substantially reduce time and energy costs of searching for prey. Invertebrates made more accessible by foraging Gray Whales could represent an important food source for murrelets during the breeding season, which coincides with the time period that whales are in the area (Murison *et al.* 1984, Henkel *et al.* 2003).

Although Marbled Murrelets off Vancouver Island are primarily limited by reduced nesting habitat, varying oceanic conditions may also cause changes in distribution and abundance (Burger & Chatwin 2002). Invertebrates made more available by Gray Whales could provide an important food source. However, invertebrates are a relatively low-energy food source, whereas murrelets have historically foraged on high-energy fish species, primarily *Ammodytes hexapterus* (Sealy 1975). Stable isotope studies of Marbled Murrelet feathers indicate that, coinciding with declines in fisheries, their diets have declined by nearly half a trophic level over the last century, with their current diets consisting of lower-energy prey, such as zooplankton (Becker & Beissinger 2005). Furthermore, oceanographic conditions in 2005 were anomalous. A lack of cold water upwelling meant fewer nutrients were available and plankton levels were reduced by more than half, which may have led to a lower abundance of fish as available prey for seabirds (W. Peterson, NOAA, pers. comm.). Large numbers of several species of seabirds, including cormorants *Phalacrocorax* spp., Common Murres *Uria aalge*, and Cassin's Auklets *Ptychoramphus aleuticus* were found dead along the coast from California to British Colombia. Both Triangle Island, British Columbia, and the Farallon Islands, California, experienced an unusually high frequency of nesting failures (Sydeman *et al.* 2006). Therefore, the association of murrelets with Gray Whales could have been stronger than usual, if it is a foraging tactic used more when primary food sources are less abundant. Associating with Gray Whales could therefore represent a strategy that allows seabirds such as murrelets to buffer extreme variability in their primary food sources. Understanding the role of these facilitative interactions will be critical in understanding the dynamics of marine food webs and evaluating potential impacts of environmental change on marine ecosystem ecology (Bruno *et al.* 2002). Further study is needed to elucidate the precise type and nature of the murrelet–whale association.

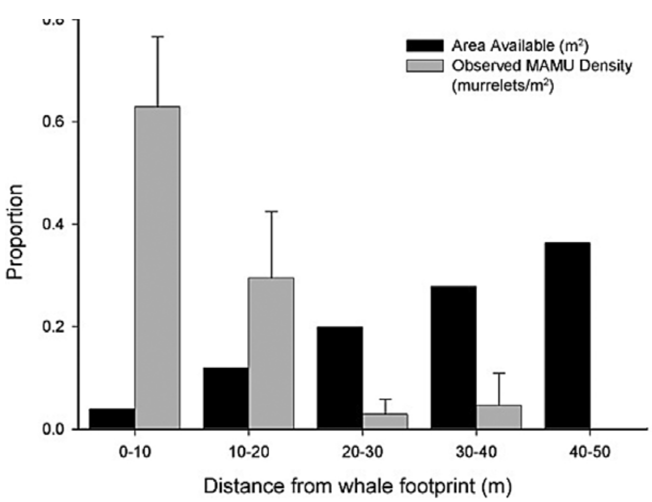

Fig. 5. Proportion of Marbled Murrelet density (murrelets/m², in gray) and available surface area (black) with respect to distance from footprints of surfacing Gray Whales, averaged across fine-scale (50 m) scans, indicating close association of murrelets and whales. Error bars are 95% confidence intervals. A total of 93 murrelets were counted during fine-scale observations.

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REFERENCES

AU, D.W.K. & PITMAN, R.L. 1986. Seabird interactions with dolphins and tuna in the eastern Pacific. *Condor* 88: 304-317.

BECKER, B.H. & BEISSINGER, S.R. 2005. Centennial decline in the trophic level of an endangered seabird after fisheries decline. *Conservation Biology* 20: 470-479.

BRUNO, J.F., STACHOWICZ, J.J. & BERTNESS, M.D. 2002. Inclusion of facilitation into ecological theory. *Trends in Ecology and Evolution* 18: 119-125.

BURGER, A.E. & CHATWIN, T.A. 2002. Multi-scale studies of populations, distribution, and habitat associations of Marbled Murrelets in Clayoquot Sound, British Columbia. Victoria, BC: Ministry of Water, Land, and Air Protection.

BURGER, A.E., HITCHCOCK, C.L. & DAVOREN, G.K. 2004. Spatial aggregations of seabirds and their prey on the continental shelf off SW Vancouver Island. *Marine Ecology Progress Series* 283: 279-292.

BURKETT, E.E. 1995. Marbled Murrelet food habits and prey ecology. In: Ralph, C.J., Hunt Jr., G.L., Raphael, M.G. & Piatt, J.F. (Eds.) Ecology and conservation of the Marbled Murrelet. General Technical Report 15. Albany, CA: USDA Forest Service. pp. 223-246.

CARTER, H.R. 1984. At-sea biology of the Marbled Murrelet (*Brachyramphus marmoratus*) in Barkley Sound, British Columbia [MSc thesis]. Winnipeg: University of Manitoba.

HARRISON, C.S. 1979. The association of marine birds and feeding Gray Whales. *Condor* 81: 93-95.

HENKEL, L.A., BURKETT, E.E. & TAKEKAWA, J.Y. 2003. At-sea activity and behavior of a radio-tagged Marbled Murrelet in central California. *Waterbirds* 26: 9-12.

HOBSON, K.A. 1990. Stable isotope analysis of Marbled Murrelets: evidence for freshwater feeding and determination of trophic level. *Condor* 92: 897-903.

HOBSON, K.A, PIATT, J.F. & PITOCCHELLI, J. 1994. Using stable isotopes to determine seabird trophic relationships. *Journal of Animal Ecology* 63: 786-798.

KRASNOW, L. & SANGER, G.A. 1982. Feeding ecology of marine birds in the nearshore waters of Kodiak Island. In: Environmental assessment of the Alaska continental shelf. Annual reports of principal investigators, Vol. 45 (1986). Boulder, CO: NOAA Environmental Research Lab. pp. 505-612.

MEHLUM, F., HUNT JR., G.L., DECKER, M.B. & NORDLUND, N. 1998. Hydrographic features, cetaceans and the foraging of Thick-billed Murres and other marine birds in the Northwestern Barents Sea. *Arctic* 5: 243-252.

MURISON, L.D., MURIE, D.J., MORIN, K.R. & de la Silva Curiel, J. 1984. Foraging of the Gray Whale along the west coast of Vancouver Island, British Colombia. In: Jones, M. L, Swarts, S.L. & Leatherwood, S. (Eds.) The Gray Whale: *Eschrichtius robustus*. Orlando, FL: Academic Press. pp. 451-462.

NERINI, M. 1984. A review of Gray Whale feeding ecology. In: Jones, M.L, Swarts, S.L. & Leatherwood, S. (Eds.) The Gray Whale: *Eschrichtius robustus*. Orlando, FL: Academic Press. pp. 423-448.

OBST, B.S. & HUNT, G.L. 1990. Marine birds feed at Gray Whale mud plumes in the Bering Sea. *Auk* 107: 678-1990.

PIEROTTI, R. 1988. Associations between marine birds and mammals in the northwest Atlantic Ocean. In: Burger, J. (Ed.) Seabirds and other marine vertebrates. New York: Colombia University Press. pp. 31-58.

PORTER, J.M. & SEALY, S.J. 1982. Dynamics of seabird multi species feeding flocks: age-related feeding behaviour. *Behaviour* 81: 91-109.

SANGER, G.A. 1987. Winter diets of Common Murres and Marbled Murrelets in Kachemak Bay, Alaska. *Condor* 89: 426-430.

SCHNEIDER, D.C. 1990. Spatial autocorrelation in marine birds. *Polar Research* 8: 87-89.

SEALY, S.G. 1975. Feeding ecology of the Ancient and Marbled murrelets near Langara Island, British Colombia. *Canadian Journal of Zoology* 53: 418-433.

SOKAL, R.R. & WARTENBERG, D.E. 1983. A test of spatial autocorrelation analysis using an isolation-by-distance model. *Genetics* 105: 219-237.

STELLE, L.L. 2002. Behavioral ecology of summer resident Gray Whales (*Eschrichtius robustus*) feeding on mysids in British Colombia, Canada [PhD thesis]. Los Angeles: University of California.

SYDEMAN, W.J., BRADLEY, R.W., WARZYBOK, P., ABRAHAM, C.L., JAHNCKE, J., HYRENBACH, K.D., KOUSKY, V., HIPFNER, J.M. & OHMAN, M.D. 2006. Planktivorous auklet *Ptychoramphus aleuticus* responses to the anomaly of 2005 in the California current. *Geophysical Research Letters* 33: L22S09.

VAN FRANEKER, J.A., VAN DEN BRINK, N.W., BATHMANN, U.V., POLLARD, R.T., DE BAAR, H.J.W. & WOLFF, W.J. 2002. Responses of seabirds, in particular prions (*Pachyptila* sp.), to small-scale processes in the Antarctic Polar Front. *Deep-Sea Research* 49: 3931-3950.

VERMEER, K. & MORGAN, K.H. 1992. Marine bird populations and habitat use in a fjord on the west coast of Vancouver Island. In: Vermeer, K., Butler, R.W. & Morgan, K.H. (Eds.) The ecology, status, and conservation of marine and shoreline birds on the west coast of Vancouver Island. Occasional Paper No. 75. Ottawa: Canadian Wildlife Service. pp. 85-95.