

**HABITAT CORRELATES OF WINTERING SEA DUCK  
OCCURRENCE IN SOUTHEAST ALASKA**

by

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## ABSTRACT

Southeast Alaska provides non-breeding habitat for >300,000 sea ducks, however little is known about habitat features that may influence their distribution within this area. We used an autologistic regression model to examine relationships between 10 species of sea ducks that winter in Southeast Alaska [harlequin duck (*Histrionicus histrionicus*), red breasted merganser (*Mergus serrator*), common merganser (*Mergus merganser*), bufflehead (*Bucephala albeola*), Barrow's goldeneye (*Bucephala islandica*), common goldeneye (*Bucephala clangula*), long-tailed duck (*Clangula hyemalis*), white winged scoter (*Melanitta fusca*), surf scoter (*Melanitta perspicillata*), and black scoter (*Melanitta nigra*)] and nearshore habitat features. Habitat features that explained sea duck occurrence included shoreline exposure, distance to streams, number of islets, percentage of rocky substrate and intertidal width. Our results suggest certain features that managers could identify during attempts to mitigate the environmental impacts of new development projects or to protect as important habitats.

**Keywords:** Alaska, habitat selection, presence, sea duck, winter

**Subject Terms:** Alaska Birds, Ducks – Wintering, Ducks - Habitat

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## INTRODUCTION

The archipelagos and inland waterways of Southeast Alaska (Figure 1) provide non-breeding habitat for at least 10 species of sea ducks totalling >300,000 individuals (Conant et al. 1988, Hodges et al. 2008), making the area one of North America's most important sea duck wintering regions. Despite these large numbers, little is known about the specific habitat attributes that are related to variation in abundance and distribution. This, in turn, constrains conservation efforts to protect important habitats and prevent or mitigate degradation of critical non-breeding areas.

Conservation of sea ducks and their habitats is needed given numerical declines among at least 10 of the 15 North American species of the Tribe Mergini (Sea Duck Joint Venture Management Board 2001, Dickson and Gilchrist 2002). Sea ducks are particularly vulnerable to threats during the non-breeding period when they are often in large aggregations (Sea Duck Joint Venture Management Board 2001); these threats include exposure to contaminants (Henny et al. 1995), oil spills (Esler et al. 2002), entanglement in fishing nets (Dickson and Gilchrist 2002), and habitat loss (McKinney et al. 2006). In Southeast Alaska, the large volume of marine traffic (Alaska Department of Environmental Conservation 2004) results in a high cumulative probability for accidental release of petroleum or other chemical products. Further, proposed development of transportation

infrastructure and mineral resources (Alaska Department of Transportation 2004, Szumigala and Hughes 2005) could result in human impacts to coastal habitats.

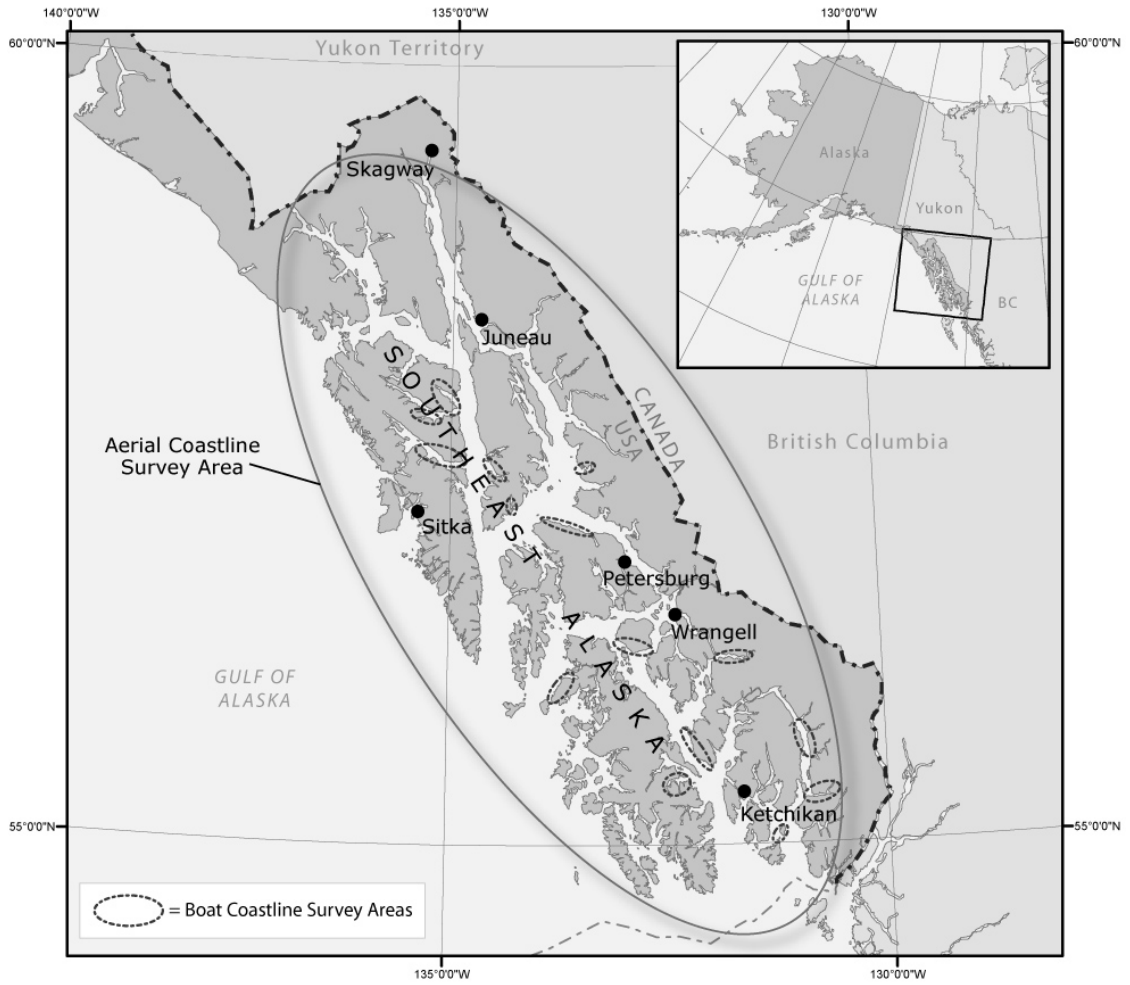
Several authors have demonstrated relationships between the abundance and distribution of wintering sea ducks and characteristics of shorelines and nearshore areas (Stott and Olson 1973; Vermeer 1982; Guillemette et al. 1992; Bustnes and Lønne 1997; Esler et al. 2000a, 2000b; Žydelis et al. 2006). These studies were at spatial scales (10s to 100s of km) that were small relative to the winter distribution of the populations. We conducted aerial surveys of the winter distribution of sea ducks at an unprecedented scale that included >23,000 km of shoreline and >1,700 km<sup>2</sup> of intertidal area in Southeast Alaska (Conant et al. 1988, Hodges et al. 2008), a region that comprises an important part of the winter range of sea ducks in the Pacific Flyway. By combining this data with geographic information on shoreline features, we quantified habitat associations of sea ducks throughout Southeast Alaska. The 10 species found in the region and considered in this study were: harlequin duck (*Histrionicus histrionicus*), red breasted merganser (*Mergus serrator*), common merganser (*Mergus merganser*), bufflehead (*Bucephala albeola*), Barrow's goldeneye (*Bucephala islandica*), common goldeneye (*Bucephala clangula*), long-tailed duck (*Clangula hyemalis*), white winged scoter (*Melanitta fusca*), surf scoter (*Melanitta perspicillata*), and black scoter (*Melanitta nigra*).

Our objectives were to identify specific shoreline habitat attributes that were related to variation in occurrence of these species of sea ducks and offer implications for subsequent conservation.

## **STUDY AREA**

Southeast Alaska (Figure 1) consists of islands, mountains, and fiords extending from 54°41' – 59°29'N and 130°28' - 137°8'W. The complex shoreline ranges from very exposed coasts with steep gradients and rocky substrates to protected inlets that have shallow gradients and fine sediments. Likewise, nearshore environments range from deepwater to broad intertidal flats. Storms are common in the Gulf of Alaska, particularly during the winter months where they often reach gale force or stronger. The region has a sparse human population with few roads, and most transportation occurs via the Alaska Marine Highway System or air travel. The land is largely federally owned within the Tongass National Forest and Glacier Bay National Park. The most significant economic sectors include tourism, government, fish harvesting and seafood processing, timber, and mining (Mehl 2008).

**Figure 1: Southeast Alaska study area for winter sea duck habitat association models 1997-2002, showing aerial coastline survey area and boat coastline survey areas.**



## **METHODS**

We used a resource selection approach to quantify sea duck habitat associations. In a resource selection study, habitat use data are compared to non-use or availability in a static and probabilistic manner (Allredge et al. 1998, Boyce and McDonald 1999). In this case, we collected sea duck presence/absence data using aerial surveys, and we derived habitat data from GIS datasets. A habitat type that is selected for is generally assumed to be of higher quality, although this interpretation should be made with some caution (Van Horne 1983, Garshelis, 2000). This type of study is widely used and has many applications in conservation and ecological management (Allredge et al. 1998, Boyce and McDonald 1999, Araujo and Gusian 2006). Several authors have identified some potential pitfalls in resource selection studies, such as selection of the appropriate modelling procedure to match the data sampling method, sample independence and spatial autocorrelation, and detectability (Allredge et al. 1998, Boyce and McDonald 1999, Garshelis 2000, Lichstein et al. 2002, Keating and Cherry 2004, MacKenzie 2006). We have addressed these concerns within the constraints of the available datasets.

## Sea Duck Counts

Sea duck observation data was collected by the US Fish and Wildlife Service. They conducted aerial surveys of sea duck distribution and abundance using a turbine-powered DeHaviland Beaver on amphibious floats for >90% of the surveys, and a Cessna 206 on amphibious floats for the remainder. They divided the Southeast Alaska coastline into four regions, and surveyed one region each winter between mid February and mid March during 1997 and 2000-2002. This resulted in coverage of >95% of the Southeast Alaska coastline, with the exception of some isolated inlets and islands, and the exposed outer coastline north of Cape Spencer. An experienced pilot and observer conducted each survey and recorded sea ducks observed on each side of the aircraft. The survey crew flew parallel to shore, approximately 50m from the shoreline, at an altitude of 35m. They recorded ducks and other waterbirds observed <400m from the shoreline; >90% of ducks were observed within this interval from the shoreline during earlier surveys (Conant et al. 1988). However, they counted all flocks of scoters regardless of their distance from shore, and where necessary diverted the aircraft offshore to observe groups of scoters. They used a modification of a flight tracking program described by Butler et al (1995) to record duck observations. They verbally recorded species group and flock size using a digital voice recording system on separate laptop computers for each observer. A Global Positioning System (GPS) receiver that was linked to the computers was used to record the flight route, and latitude and longitude of the aircraft at the time bird observations were recorded. Each computer screen displayed aircraft

position and flight track on a digital map of the shoreline. This ensured that all shoreline areas were surveyed and that no areas were surveyed more than once.

During aerial surveys, the survey team could not consistently classify scoters, goldeneyes, or mergansers to species, so observations of those taxa were combined into species groups. To assess the composition of species groups counted aerially (Table 1), the US Fish and Wildlife Service re-sampled selected areas using skiffs with outboard motors. They chose areas to re-sample based on their accessibility and to provide a representative sample of available habitat types. They attempted to survey all types of coastline by boat, however difficulty accessing the exposed outer coast by boat during the winter may have had some impact on the boat:air ratios. They counted birds in the water within the same 400m limit from shore as the air surveys, but classified birds to species where possible. They conducted boat surveys within 3 days of the air surveys over the same shoreline, and used a GPS receiver and laptop computer system similar to that described above to record the observations.

**Table 1: Proportions of individual sea duck species within species groups (%) calculated from boat-based observations in Southeast Alaska 1997-2002**

<b>Species</b>	<b>Proportion by species</b>
<b>Scoters</b>	
Surf Scoter	51.4%
White-Winged Scoter	40.1%
Black Scoter	1.4%
Unidentified Scoter	7.1%
<b>Mergansers</b>	
Red-Breasted Merganser	47.7%
Common Merganser	34.4%
Hooded Merganser	1.9%
Unidentified Merganser	16.1%
<b>Goldeneyes</b>	
Barrow's Goldeneye	76.6%
Common Goldeneye	1.4%
Unidentified Goldeneye	22.0%

Imperfect detection of species presence can lead to biased parameter estimates in resource selection studies (Moore and Swihart 2005). We were unable to estimate detection likelihoods, but Hodges et al. (2008) compared numbers of birds observed during aerial surveys to those seen during boat surveys and found that ratios ranged from 0.33 (air:boat) for long-tailed ducks to 0.92 (air:boat) for mergansers. These results indicate that non-detection was a potential problem in our datasets, and varied by species.

In a habitat selection study, the problem of non-detection is greatest where detection likelihood is influenced by site-specific covariates (Gu and Swihart 2004). If detection likelihood is equal across habitat types, the analysis still provides relative probabilities of use (MacKenzie 2006). Wind and glare were



the primary impediments to aerial observation of sea ducks – factors that occurred throughout the study and across all habitat types. We therefore assumed constant detectability across habitat types. This assumption is more likely to have a potential impact on results for species groups with lower detection rates. Laursen et al. (2008) found that species that are numerous, of wide spread occurrence, and found in large flocks are most likely to have good correspondence between aerial and ground based counts. These attributes are true of most species groups in this analysis, with the possible exception of the less numerous long-tailed ducks.

To create sample units for subsequent analysis, we summarized the sea duck observation data into circular plots using ESRI ArcGIS 9.2. We randomly selected points along the shoreline with a set minimum inter-point distance of 1800m. This minimum distance allowed for the creation of plots with a radius of 800m without overlap. We chose an 800m radius (2 km<sup>2</sup>) based on sea duck winter home range sizes, the scale of shoreline variability in the GIS habitat datasets, and the error associated with sea duck observations. Sea duck winter home range sizes vary depending on species, age, sex and mate status, however several estimates suggest a range of approximately 2 to 10 km<sup>2</sup> (Morton et al. 1989, Robertson et al. 2000, Kirk et al. 2008). We chose a plot size at the smaller end of this range to more effectively associate presence/absence with shoreline characteristics, which typically were recorded on a smaller scale (100's of meters). We did not use a smaller plot size because we estimated maximum error distance for aerial duck observations to be ~800m. This error may have

resulted because aircraft location was recorded as flocks were seen, and the aircraft location at the time of the observation could have differed somewhat from the actual site used by the flock.

We selected a total of 4060 random plots with the required inter-point distance. Within each plot, we summed the number of individuals of each species group observed during aerial surveys and converted this to presence (ducks  $\geq 1$ ) or absence (ducks = 0). This resulted in separate datasets for each species group in which plots in the random sample were either “used” by a species group or were “unused”. We observed harlequin ducks in 24%, mergansers in 38%, bufflehead in 17%, goldeneye in 44%, long-tailed duck in 5%, and scoters in 22% of random plots.

## **Habitat Attributes**

To examine relationships between sea duck presence and habitat features, we gathered data on habitat attributes that have been associated with sea duck densities in previous studies (Nilsson 1972, Stott and Olson 1973, Esler et al. 2000a, Esler et al., 2000b, Žydelis et al. 2006) and were available in a Geographic Information System (GIS) format for Southeast Alaska. We assessed correlations between potential habitat variables using variance inflation factors [VIF; (Belsley et al.1980)] and eliminated highly related variables to avoid multicollinearity. We selected six environmental parameters with low levels of correlation (VIF<2). These variables were: shoreline exposure to high energy waves; distance to the outer coast; distance to a large stream (>5km in length);

number of islets (<1ha in size) present; percentage of shoreline substrate that was rocky; and intertidal width (Table 2).

The Nature Conservancy (TNC) – Alaska Chapter created several of the GIS datasets that we used in our models. They summarized exposure, substrate type, and intertidal width for linear shoreline segments at 1:63,360 or higher resolution (Albert & Schoen 2007). Albert and Schoen (2007) calculated exposure based on potential fetch for a given shoreline segment. They created 4 rankings of exposure ranging from very protected (indicated as 10) to very exposed (indicated as 40). Albert and Schoen (2007) derived substrate type and intertidal width from the NOAA Environmental Sensitivity Index (NOAA 2002) and the Biophysical Shore Zone Mapping System (Howes et al. 1994).

Virtually all of the very exposed shoreline occurred on the outer coast of Southeast Alaska, therefore we used Albert and Schoen’s (2007) exposure rankings to create the “distance to exposed outer coastline” parameter which was a measure of broad scale geography. We extracted stream data from the National Hydrography Dataset (US Geological Survey), and islet data from the Alaska Department of Natural Resources, Land Records Information Section, Alaska Coastline 1:63,360 (Alaska Department of Natural Resources 1998).

We summarized habitat data for each of the same 4060 circular plots as the sea duck observation data (described above). To create a single value for intertidal width and exposure in each plot, we calculated a weighted average based on shore segment length. We summarized substrate type as the percentage of shoreline in the plot that was classified as “rocky” (rock platform,

rock with gravel, rock with sand and gravel, or rocky shore/cliff) compared to other substrate types such as sandy beach or tidal flat  $[(\text{rocky length}/\text{total shoreline length}) \times 100]$ . The presence of reefs, which is an important habitat feature for some sea ducks (Esler et al. 2000a), was not available; therefore we used the presence of islets smaller than 1ha as a surrogate. We counted the number of islets <1ha in each plot. We calculated the “distance to very exposed outer coast” as the distance from the centre of each plot to the nearest segment of very exposed shoreline, which occurred only on the outer coast. We measured distance to streams that were >5 km long, because smaller streams were so abundant that they were present in the vast majority of plots and therefore would not provide meaningful discrimination between used and unused plots. We computed mean values of habitat parameters within random plots (Table 3) for comparison with sea duck habitat features in other geographic areas.

**Table 2: Habitat parameters created through GIS analysis for the Southeast Alaska coastline**

<b>Code</b>	<b>Name</b>	<b>Description</b>	<b>Source</b>	<b>Units</b>
Autocov	Autocovariate	Parameter calculated to account for spatial autocorrelation	Calculated from sea duck observation data	-
Exp	Exposure	Degree of exposure to wind and waves. 4 ranks: very protected (10), semi-protected (20), semi-exposed (30) and very exposed (40).	Albert and Schoen 2007	Ranking
DtoExp	Distance to very exposed coast	Distance from the center of the plot to the nearest segment of very exposed shoreline (which occurred only on the outer west coast)	Calculated from exposure data	Km
DtoStream	Distance to large stream	Distance to the nearest stream that was >5km in length	Counted from National Hydrography Dataset	Km
Islets	Number of islets >1ha	Number of islets in the plot that were 1ha or smaller in area	Calculated from the Alaska DNR coastline dataset	-
Rock	Percentage of Rocky Substrate Classes	The percentage of shoreline (by length) in the plot that was classified as rock platform, rock with gravel, rock with sand and gravel, or rocky shore/cliff	Calculated from shoreline substrate dataset created by Albert and Schoen 2007	%
Width	Intertidal width	Average intertidal width of all shorelines in the plot	Albert and Schoen 2007	m

**Table 3: Habitat values calculated for the Southeast Alaska region within aerial survey plots (2km<sup>2</sup>) 2007**

	<b>Distance to Exposed Outer coast (km)</b>	<b>Distance to streams &gt; 5km (km)</b>	<b>Exposure Ranking</b>	<b>Intertidal Width (m)</b>	<b>Number of Islets &lt;1ha per plot</b>	<b>Percent Rocky Classes %</b>
MEAN	50.0	10.4	19.8	81.7	2.2	31
STD DEV	36.3	11.4	76.0	38.9	4.6	33
MIN	0.0	0.0	10.0	5.2	0.0	0
MAX	147.4	119.7	40.0	1893.5	67.0	100
MEDIAN	46.1	7.9	20.0	46.9	0.0	18

## **Statistical Analysis**

For each species group we used logistic regression to evaluate the relationships between habitat attributes and the probability of presence of sea ducks observed in random plots during aerial surveys. We used the Proc Logistic procedure in SAS 9.1 (SAS, Cary, North Carolina) to run the logistic regression analysis. We included an offset in the models calculated as  $\log(\text{area surveyed})$ , so that the probability of sea duck presence was proportional to the area in the plot that was surveyed. Area surveyed for a given plot was calculated as the marine area within 400 m of the shoreline.

## **Spatial Autocorrelation**

Species abundances are often positively spatially autocorrelated, whether due to exogenous processes such as environmental attributes, or endogenous processes such as conspecific attraction (Legendre 1993). Autocorrelated data violate the assumption of independence required for most statistical methods and can increase the occurrence of Type I errors (Legendre et al. 2002). A number of methods have been devised to deal with this problem, however there is yet to be an established “best” method in the literature (Dormann et al. 2007, Hawkins et al. 2007, Miller et al. 2007).

As an initial assessment of spatial autocorrelation, we calculated Moran’s I correlograms (Cliff and Ord 1981; Python Version 2.4) for sea duck presence in each species group, and for each of the habitat attributes. We then calculated Moran’s I correlograms for residuals from global habitat models for each species

group. For each of these calculations, we used 18 equal interval distance categories of 34 km.

Moran's I is an indication of the degree and direction of spatial autocorrelation that ranges from -1 (perfectly dispersed) to +1 (perfectly clustered). A value of 0 indicates a random spatial pattern. A Moran's I correlogram displays Moran's I values calculated across a series of distance classes.

Moran's I correlograms of sea duck presence by plot indicated spatial autocorrelation in all species groups. Spatial autocorrelation was greatest in the smallest distance class, and was positive with maximum values of 0.25 for scoters to 0.35 for harlequin ducks. Mid-range distance classes displayed negative spatial autocorrelation, but with small Moran's I values. Habitat attributes were also spatially correlated with maximum Moran's I values of 0.52 in the smallest distance class for "distance to streams" to 0.23 in the smallest distance class for "intertidal width".

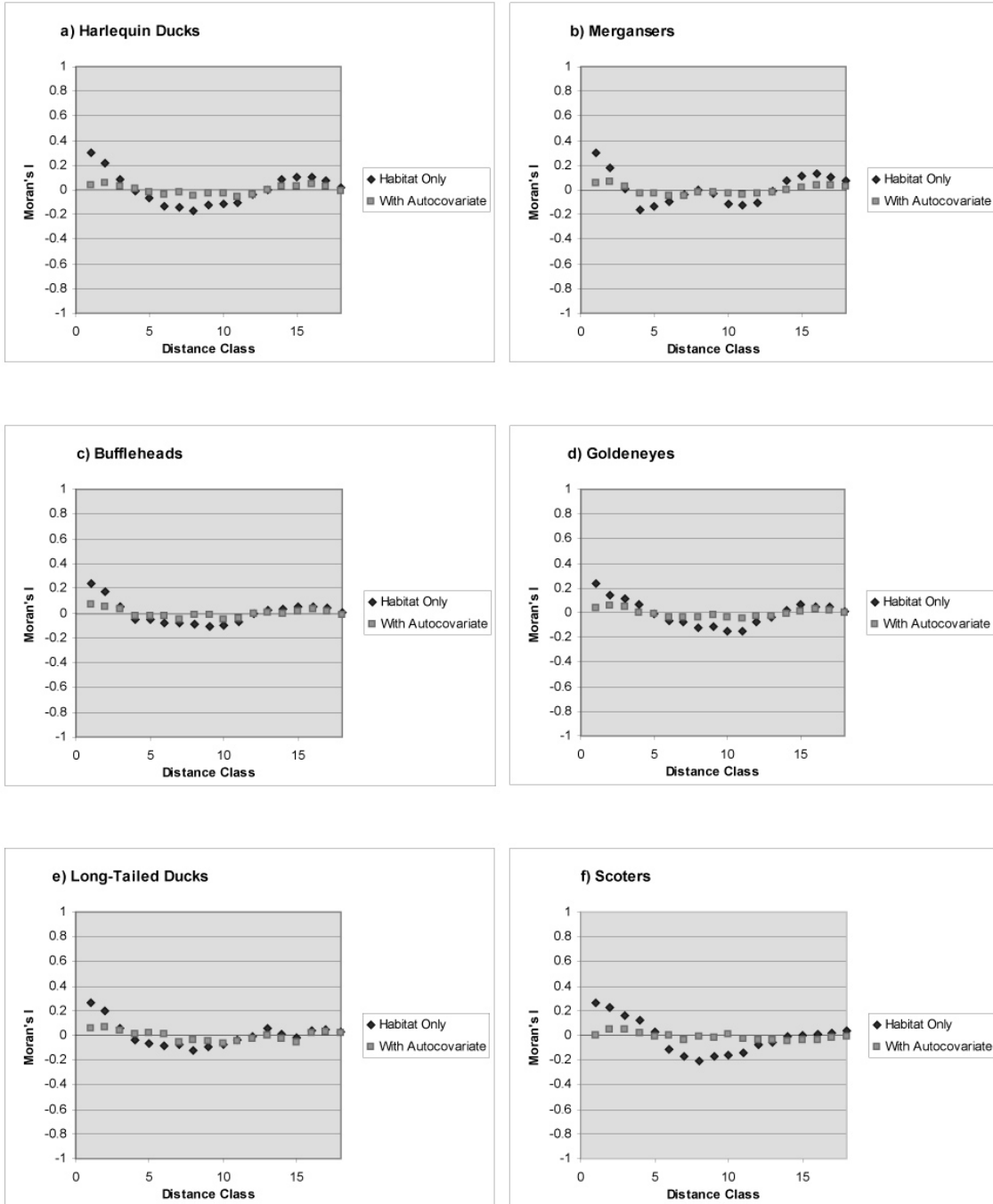
To mitigate the consequences of spatial autocorrelation, we included an autocovariate in our models - a distance-weighted function of neighbouring response values. This type of model is often referred to as an autologistic model (Augustin et al. 1996, Moore and Swihart 2005, Wintle and Bardos 2006). We calculated the autocovariate as:

$$autocov_i = \frac{\sum_{j=1}^{k_i} w_{ij} y_j}{\sum_{j=1}^{k_i} w_{ij}}$$

where  $k_i$  is the number of neighbouring plots of plot  $i$  that are considered in the analysis,  $w_{ij}$  is the weight of an individual neighbour, and  $y_j$  is the value of that neighbour (1 for sea duck presence, 0 for absence). The weight of an individual neighbour  $j$  is  $w_{ij} = 1/h_{ij}$ , where  $h_{ij}$  is the Euclidean distance between the centre of plots  $i$  and  $j$ . (Augustin et al. 1996). Due to the large area covered in this analysis, we were not able to select the number of neighbours to include in the analysis based on the maximum distance at which spatial autocorrelation occurred (Figures 2 a-f) (Moore and Swihart 2005). The large number of neighbours would have made computation laborious, and the benefit gained from inclusion of additional neighbours decreases as the distance from the plot in question increases. Instead, we traded off the neighbourhood size against computation time, and settled on a neighbourhood of 20 plots. Inclusion of an autocovariate term reduced the degree of spatial autocorrelation in the residuals for all models (Figure 2a-f).



**Figure 2 (a-f): Moran's I correlograms of residuals from global models of sea duck presence by species group in Southeast Alaska 1997-2002 showing the differences between models that only included habitat variables and those that included an autocovariate term. Each distance class is 34 km.**



## Model Selection and Inference

We used an information-theoretic approach to data analysis and interpretation (Burnham and Anderson 2002). For each species group, we examined a set of candidate models that included all additive combinations of the explanatory variables, and calculated Akaike's Information Criterion (AIC) for each candidate model to identify the most parsimonious models. We modified code originally created by Schaffer (2004) to output the AIC results from SAS 9.1. For each model, we calculated the difference in AIC from the best model ( $\Delta\text{AIC}$ ) and AIC weights, both of which indicate the relative degree of support among models. We also calculated parameter likelihoods, which is the sum of AIC weights for all models including a given parameter; this metric provides a measure of support for the value a given variable has for explaining variation in the response (i.e. duck presence), ranging from 0 (no support) to 1 (strong support). We calculated model averaged parameter estimates and standard errors, and finally converted the parameter estimates to odds ratios (odds ratio =  $e^{|\text{parameter estimate}|}$ ). A parameter estimate in logistic regression provides the amount of change in the log-odds of the dependent variable (in this case presence) for each unit change in the independent variable (e.g. number of islets). The odds ratio provides the amount of change in the odds of the dependent variable for each unit change in the independent variable.

To draw inference about the relationships between sea duck presence and shoreline habitat attributes, we considered the AIC ranking of the models and the model averaged parameter estimates and weights. Cases in which many

models had similar AIC values and model weights indicated a high degree of model uncertainty; conversely, larger differences in AIC and high model weights for one or a small number of models indicated that those models had significantly greater explanatory value than others. We considered specific habitat attributes to be associated with sea duck presence where they were present in well-supported models, had high parameter weights, and parameter estimates were  $>2$  SE.

### **Model Evaluation**

We evaluated the models against a second unique set of plots created from the original sea duck observation and habitat datasets. We randomly selected the evaluation plots using ArcGIS 9.2, based on the criteria that they must not overlap with the original plots. This resulted in separate dataset for the 6 species groups, consisting of 890 new plots, and with habitat features calculated in the same manner as the original datasets. Of these plots, harlequin ducks were present in 19%, mergansers in 29%, buffleheads in 14%, goldeneyes in 38%, long-tailed ducks in 4%, and scoters in 15%.

We compared the model's predictions to actual observations using "receiver operating characteristic" (ROC) curves for the logistic models (Hanley and McNeil 1982, Fielding and Bell 1997). The area under the ROC curve (AUC) provides a single measure of accuracy that is threshold independent. The AUC varies between 0.5 and 1; an AUC value of 0.5 indicates random prediction, whereas a value of 1.0 indicates perfect prediction. For our model evaluation, we

considered AUC values of 0.90-1 as excellent, 0.80-0.90 as good, 0.70-0.80 as fair, 0.60-0.70 as poor, and  $<0.60$  as inadequate.

## **RESULTS**

### **Habitat Associations of Species Groups**

There was no single best supported model that predicted sea duck presence based on shoreline habitat features among any of the 6 species groups that we examined. The number of models that fell within  $\Delta AIC \leq 2$  ranged from 3 for bufflehead to 10 for long-tailed ducks (Table 4). In no case did model weight for the best supported model in a candidate set exceed 0.5. Inclusion of the autocovariate term was strongly supported, as it appeared in the best-supported models for all species groups (Table 4). However, a model that included just the autocovariate term was only supported for long-tailed ducks, indicating that for most species there was explanatory value to be gained by including habitat parameters to predict their presence.

### **Harlequin Ducks**

The parameters percentage of rocky shoreline and shoreline width appeared in each of the 5 top models for harlequin ducks, whereas the number of islets appeared in 4 out of 5 models and shoreline exposure in 2 of the top 5 models (Table 4). Based on model averaged parameters that had weights  $>0.5$  and estimates that were  $>2$  SE, presence of harlequin ducks was positively influenced by the percentage of rocky shoreline, and negatively influenced by intertidal width (Table 5). The odds of harlequin duck presence increased by 1.8

for every increase in percent rocky shoreline, and decreased by 1.005 for every meter of increase in shoreline width (Table 5). Although parameter estimates were  $<2$  SE, the number of islets in a random plot and shoreline exposure were positively related to harlequin duck presence. The odds of harlequin duck presence increased by 1.013 for every additional islet and by 1.004 for every unit increase in exposure rank. The best harlequin duck model had a fair discriminatory level with an AUC value of 0.76.

## **Mergansers**

The parameters distance to streams, shoreline exposure, and percent rocky shoreline were present in each of the top 4 models for mergansers (Table 4), and each had parameter weights  $> 0.9$  and parameter estimates that were  $>2$ SE (Table 5). Distance to streams was negatively related to merganser presence, meaning that presence was more likely when streams were closer. The odds of merganser presence increased by 1.009 for every kilometre closer the plot centre was to a large stream. Merganser presence was negatively related to shoreline exposure, and the odds of merganser presence increased by 1.058 for every unit decrease in exposure ranking. Mergansers were more likely to be present on rocky shorelines and their odds of being present in a random plot increased by 1.48 for every percentage increase in rocky shoreline. Intertidal width was in 3 of the top 4 models, but had a parameter estimate that was  $<2$  SE. Intertidal width was negatively related to merganser presence; the odds of merganser presence increased by 1.002 for every unit decrease in

meters of intertidal width. The best merganser model had a poor discriminatory level with an AUC value of 0.63.

## **Buffleheads**

The parameters distance to streams, exposure, islets, and intertidal width, were in each of the top models for bufflehead (Table 4). Each of these parameters had parameter weights close to 1, and parameter estimates that were  $>2$  SE (Table 5). Bufflehead presence was negatively associated with distance to streams, meaning that buffleheads were more likely to be present where streams were closer. The odds of bufflehead presence increased by 1.02 for every kilometre closer the plot centre was to a large stream. Buffleheads were less likely to be present near exposed shorelines, and the odds of bufflehead presence increased by 1.051 for every unit decrease in the exposure ranking. Buffleheads were also more likely to be present in plots with more islets and where shorelines were wider. The odds of bufflehead presence increased by 1.04 for every increase in number of islets, and by 1.008 for every meter increase in intertidal width. The best bufflehead model had a good discriminatory level with an AUC value of 0.80.

## **Goldeneyes**

The parameters distance to streams and shoreline exposure appeared in each of the top models for goldeneye presence (Table 4), and each had parameter weights  $>0.90$  and parameter estimates  $>2$  SE (Table 5). As with bufflehead and mergansers, goldeneye were more likely to be present where streams were

closer. The odds of goldeneye presence increased by 1.02 for every kilometre closer the plot centre was to a large stream. Goldeneye were less likely to be present in plots with exposed shorelines, and their odds of occurrence increased by 1.062 for every unit decrease in the exposure ranking. The best goldeneye model had a poor discriminatory ability with an AUC value of 0.67.

## **Long-Tailed Ducks**

There was more model uncertainty for long-tailed ducks than any other species group. Only the autocovariate term appeared in each of the top 10 models. It was the only parameter in the top model, the only parameter with a weight  $>0.90$ , and the only parameter in which the estimate was  $>2$  SE. The parameter weights for habitat variables were  $< 0.50$  and the odds of long-tailed duck presence changed only very slightly with changes in the habitat parameters. The largest relationship was for percent rocky shoreline, where the odds of long-tailed duck presence increased by 1.14 for every percentage decrease in rocky shoreline, but this value was small when compared with the other species groups. Despite the poor predictive contributions of habitat variables, the best long-tailed duck model had a fair discriminatory ability with an AUC value of 0.77.

## **Scoters**

The parameters shoreline exposure and islets occurred in each of the top 5 models for scoters (Table 4). Only shoreline exposure had a parameter weight  $>0.90$  and a parameter estimate  $>2$  SE (Table 5). Scoters were less likely to be present in plots with exposed shorelines and the odds of scoter presence



increased by 1.029 for every unit decrease in exposure ranking. Scoter presence was positively related to the number of islets and the parameter weight was 0.84. However the parameter estimate was  $< 2SE$  and the odds of scoter presence increased by only 1.02 for each increase in the number of islets. The best scoter model had a fair level of discriminatory ability with an AUC value of 0.71.

**Table 4: Model selection results for logistic models of sea duck presence/absence in Southeast Alaska with  $\Delta AIC < 2$  1997-2002.**

<b>Model, by Species</b>	<b>Delta AIC</b>	<b>Weight</b>	<b>Parameters</b>
<b>Harlequin Ducks</b>			
Width + Islets + Rock + HAutocov	0.00	0.183	5
Width + Exp + Islets + Rock + HAutocov	0.66	0.132	6
Width + Exp + Islets + Rock + DtoStream + HAutocov	1.05	0.109	7
Width + Islets + Rock + DtoStream + HAutocov	1.11	0.105	6
Width + Rock + HAutocov	1.98	0.068	4
<b>Mergansers</b>			
Exp + Islets + Rock + DtoStream + MAutocov	0.00	0.332	6
Width + Exp + Islets + Rock + DtoExp + DtoStream + MAutocov	1.22	0.181	8
Width + Exp + Rock + DtoStream + MAutocov	1.63	0.147	6
Width + Exp + Rock + DtoExp + DtoStream + MAutocov	1.76	0.138	7
<b>Buffleheads</b>			
Width + Exp + Islets + DtoStream + BAutocov	0.00	0.488	6
Width + Exp + Islets + DtoExp + DtoStream + BAutocov	1.68	0.211	7
Width + Exp + Islets + Rock + DtoStream + BAutocov	1.74	0.204	7
<b>Goldeneyes</b>			
Exp + DtoStream + GAutocov	0.00	0.164	4
Exp + Rock + DtoStream + GAutocov	0.09	0.156	5
Width + Exp + DtoStream + GAutocov	0.86	0.106	5
Width + Exp + Rock + DtoStream + GAutocov	1.13	0.093	6
Exp + Islets + Rock + DtoStream + GAutocov	1.82	0.066	6
Exp + Islets + DtoStream + GAutocov	1.92	0.063	5
Exp + DtoExp + DtoStream + GAutocov	1.97	0.061	5
<b>Long-Tailed Ducks</b>			
LAutocov	0.00	0.076	2
Rock + LAutocov	0.18	0.069	3
Exposure + LAutocov	0.94	0.047	3
Width + Rock + LAutocov	1.10	0.044	4
Width + LAutocov	1.33	0.039	3
Islets + Rock + LAutocov	1.33	0.039	4
Islets + LAutocov	1.58	0.035	3
DtoExp + LAutocov	1.90	0.029	3
DtoStream + LAutocov	1.92	0.029	3
Width + Exp + LAutocov	1.94	0.029	4
<b>Scoters</b>			
Exp + Islets + SAutocov	0.00	0.206	4
Exp + Islets + DtoStream + SAutocov	1.49	0.098	5
Width + Exp + Islets + SAutocov	1.53	0.096	5
Exp + Islets + DtoExp + SAutocov	1.89	0.080	5
Exp + Islets + Rock + SAutocov	1.99	0.076	5

**Table 5: Parameter weights and model averaged parameter estimates for sea ducks by species group in Southeast Alaska 1997-2002. W = parameter weight, E = weighted parameter estimate, SE = standard error of the weighted parameter estimate, and OR = Odds Ratio. Items in bold are parameter weights > 0.50 and parameter estimates  $\geq 2*SE$**

parameter	Harlequin Ducks				Mergansers			
	W	E	SE	OR	W	E	SE	OR
Intercept		-2.595	0.010			-0.754	0.152	
Autocov	<b>0.977</b>	<b>4.248</b>	0.179	70.00	<b>0.857</b>	<b>3.521</b>	0.175	33.83
Exp	0.445	0.004	0.006	1.004	<b>1.000</b>	<b>-0.056</b>	0.006	1.058
DtoExp	0.285	-0.000	0.000	1.000	0.391	-0.001	0.001	1.000
DtoStream	0.356	-0.002	0.003	1.002	<b>0.911</b>	<b>-0.010</b>	0.005	1.010
Islets	<b>0.749</b>	0.013	0.010	1.013	0.636	0.009	0.009	1.009
Rock	<b>0.997</b>	<b>0.589</b>	0.151	1.802	<b>0.953</b>	<b>0.391</b>	0.148	1.479
Width	<b>0.971</b>	<b>-0.004</b>	0.002	1.004	<b>0.892</b>	<b>-0.002</b>	0.001	1.002

parameter	Buffleheads				Goldeneyes			
	W	E	SE	OR	W	E	SE	OR
Intercept		-1.714	0.155			-0.388	0.153	
Autocov	<b>1.000</b>	<b>4.844</b>	0.273	127.027	<b>0.907</b>	<b>3.452</b>	0.177	31.57
Exp	<b>1.000</b>	<b>-0.05</b>	0.007	1.051	<b>1.000</b>	<b>-0.060</b>	0.006	1.062
DtoExp	0.302	0.000	0.001	1.000	0.273	0.000	0.000	1.000
DtoStream	<b>0.992</b>	<b>-0.020</b>	0.006	1.020	<b>1.000</b>	<b>-0.022</b>	0.005	1.022
Islets	<b>0.999</b>	<b>0.038</b>	0.009	1.039	0.287	0.001	0.003	1.001
Rock	0.296	-0.029	0.080	1.029	0.486	-0.090	0.127	1.095
Width	<b>1.000</b>	<b>0.008</b>	0.001	1.008	0.383	0.000	0.001	1.000

parameter	Long-Tailed Ducks				Scoters			
	W	E	SE	OR	W	E	SE	OR
Intercept		-3.653	0.203			-2.132	0.144	
Autocov	<b>0.979</b>	<b>8.342</b>	0.488	4197	<b>0.996</b>	<b>5.169</b>	0.219	175.6
Exp	0.342	0.003	0.007	1.000	<b>1.000</b>	<b>-0.029</b>	0.006	1.029
DtoExp	0.277	0.000	0.001	1.000	0.292	0.000	0.001	1.000
DtoStream	0.257	0.000	0.002	1.000	0.328	0.001	0.002	1.001
Islets	0.342	0.005	0.010	1.005	<b>0.839</b>	0.018	0.011	1.018
Rock	0.462	-0.152	0.226	1.164	0.274	0.007	0.050	1.007
Width	0.371	-0.001	0.001	1.000	0.314	0.000	0.001	1.000

## DISCUSSION

The underlying goal of studying habitat selection is to learn about species' ecological requirements and where appropriate, to use this information for management purposes (Boyce and McDonald 1999, Araujo and Guisan 2006, Thomas and Taylor 2006). To achieve this, we assume that the habitat associations observed reflect the trade-offs an animal makes in selecting appropriate habitat. While it may be difficult to draw an absolute inference between habitat selection and fitness without measuring fitness directly (Garshelis 2000), habitat selection studies provide guidance on which to base management decisions. The relationships may be different for different geographic areas depending on the habitats available and the relationships between habitat features, and may be different at different scales (Garshelis 2000, Krebs et al. 2007). Five of the six groups of sea ducks we examined were associated with at least one of the habitat features we measured. Of the six environmental parameters, only one, distance to the exposed outer coast, was not strongly associated with any group of sea duck.

Spatial autocorrelation was present for all species, particularly at finer scales, and the autocovariate parameter was a significant predictor of presence in all models. Spatial autocorrelation can be due to both internal and external factors (Legendre and Legendre 1998). Sea ducks are gregarious birds, particularly during the non-breeding season (Nilsson 1972). However the scale at

which we analyzed spatial autocorrelation (18 distance classes of 34 km each), and the fact that positive spatial autocorrelation was found in several of the shorter distance classes suggests that conspecific attraction was not the only explanation. The remainder may be attributed to habitat attributes, some that we measured, and some that we did not measure.

The ability of the models to predict sea duck presence varied between poor and good for the six groups examined. Limitations of the models stemmed from several sources: error introduced as a result of the data collection and analysis processes, environmental variables that were not measured and available in GIS format, the aggregation of several species into one species group, or possibly errors in the form of the models (e.g. relationships that were multiplicative rather than additive). Environmental variables that we would have liked to include were reefs (Esler et al. 2000a, Rodway et al. 2003), prey biomass (Kaiser et al. 2006), and salinity (Nyström and Pehrsson 1988), each of which has the potential to influence sea duck distributions or fitness. Despite these limitations, the data were adequate for our primary intent, which was to examine basic relationships at a very large spatial scale.

## **Harlequin Ducks**

Harlequin ducks were associated with rockier shorelines of a narrower width, and with the presence of islets. They also may have been associated with higher levels of exposure and shorter distances to streams. These findings support two previous studies of harlequin duck winter habitat associations, but are in contrast to a third study.

Esler et al. (2000a) found that harlequin ducks densities were positively associated with short distances to streams and reefs, a high degree of exposure, and to a lesser degree, mixed substrates. Goudie and Ankney (1988) noted that harlequin ducks tended to be found near reefs more often than other species in Newfoundland. The exception was a study by Rodway et al. (2003) in the Strait of Georgia, British Columbia who found that harlequin ducks tended to be associated with wide intertidal areas and areas without streams, in addition to mixed or rocky substrate and small offshore islets.

Rockier shorelines likely provide the greatest availability of the benthic invertebrates on which harlequin ducks primarily feed (Vermeer 1983). Shoreline width could affect the abundance of benthic invertebrates (vertical cliffs would provide less habitat for benthic invertebrates than a wider intertidal zone), however very wide intertidal areas are more likely to be sandy or muddy which is less optimal for the benthic invertebrates on which harlequin ducks feed. That intermediate intertidal width may be most advantageous for harlequin duck foraging may explain the difference in Rodway et al's (2003) results compared to ours. The results may depend on the availability of width classes in a given geographic area. There is some agreement that harlequin ducks are associated with reefs or islets, which may be due to reduced predation risk. In some areas, harlequin ducks were associated with proximity to streams, which may reduce osmotic stress (Nystrom and Pehrsson 1988). In other areas, streams may be associated with less favourable habitat such as vertical cliffs (Rodway et al. 2003), and therefore be negatively associated with harlequin duck abundance.

## **Mergansers**

The merganser group was associated with a shorter distance to streams, less exposure, and rockier substrates. There is limited research of the winter habitat associations of mergansers with which to compare our results, and comparisons are made more difficult by the combination of several species of mergansers into one group for our study. Our boat data suggest that our model is primarily based on red-breasted mergansers, and common mergansers.

Stott and Olson (1973) reported that, in New Hampshire, red-breasted mergansers were most abundant off rocky headlands, and that smaller numbers were associated with increasing levels of sandy substrate. On the other hand, a study in Redfish Bay, Texas indicated no habitat preferences by red-breasted mergansers (Gibbons and Withers 2006). Nilsson (1972) noted that red-breasted mergansers were found over all bottom types to a depth of 15m. Holm and Burger (2002) found that mergansers in southern British Columbia preferred to forage in calm water. In summarizing several other studies, Mallory and Metz (1999) reported that common mergansers generally wintered on lakes, rivers, coastal bays or estuaries where sufficient food was available. Hooded mergansers are more likely to be found in freshwater during the winter (Dugger et al. 1994).

Our finding that wintering mergansers are associated with less exposure, proximity to streams, and narrower intertidal areas is new. Small fish, commonly consumed by both red-breasted and common mergansers (Mallory and Metz 1999, Titman 1999), occur in higher densities in these areas.

Despite these findings, the predictive ability of the best merganser model was not strong, and there are likely other important factors influencing their distribution. Future studies which incorporate prey availability and focus on a single species may be able to generate better results.

## **Buffleheads**

Buffleheads were associated with less shoreline exposure, wider intertidal areas, closer proximity to streams, and higher numbers of islets. Other studies report that bufflehead use sheltered areas including harbours and estuaries (Erskine 1972, Stott and Olson 1973). Stott and Olson (1973) also noted that they were more often found in rockier areas, whereas Erskine (1972) suggested soft bottoms were preferred.

Sheltered areas with wider intertidal widths and proximity to streams may provide good availability of the prey species on which buffleheads feed, which include shrimp, snails, amphipods, isopods, and plant seeds (Erskine 1972). It may also be easier for the small ducks to forage in less turbulent waters, and less exposure may lower the energetic costs required for thermoregulation (McKinney and McWilliams 2005). The positive relationship with islets has not previously been reported. Islets may be an indicator of more complex shorelines, which may also have more of the bays and inlets preferred by buffleheads. Further research is required to better define this relationship.

Our study did not suggest the importance of substrate type to bufflehead presence, which contrasts with the findings of both Stott and Olson (1973) and Erskine (1972). The lack of importance of this variable in our model may be due



to the resolution of our sample plots (800 m) which may not be fine enough to pick up small scale substrate preferences. Alternatively, buffleheads at the northern extent of their winter range may be more sensitive to exposure and intertidal width than to substrate type.

## **Goldeneyes**

Goldeneyes were associated with closer proximity to streams, and lower levels of exposure. Similar to our analysis of the merganser group, the goldeneye group was comprised of >1 species. However in this case, our boat observations suggest that Barrow's goldeneye were the dominant species.

Esler et al. (2000b) found that Barrow's goldeneye were associated with occurrence of a stream within 200m, lack of exposure, and mixed substrate during winter. Savard's (1988, 1989) research on Barrow's goldeneyes suggests that they were found primarily in rocky areas.

Barrow's goldeneyes consume primarily mollusks when they are in saltwater habitats (Eadie et al. 2000). Similar to harlequin ducks, they may prefer habitats with closer proximity to streams to reduce osmotic stress (Nystrom and Pehrsson 1988). Similar to buffleheads, less exposed habitats may be advantageous due to lower energetic costs required for thermoregulation (McKinney and McWilliams 2005), and possibly lower energetic costs associated with foraging in more turbulent water.

Our models do not strongly support substrate as a factor influencing goldeneye distribution, but indicate a possible weak negative interaction with percent rock. The decision of which substrate types to include in our

categorization of “rocky” may have resulted in this discrepancy. Our “rocky” habitat included rock platforms and rocky shore or cliffs in addition to mixed rock and gravel or sand. Goldeneye may have been positively associated with one or more of these categories but not with others, leading to an inconclusive result.

### **Long-tailed ducks**

The long-tailed duck was the only species in our study for which no habitat variables were associated with its presence. The only parameter with a strong AIC weight was the autocovariate, suggesting that the presence of conspecifics, or another habitat variable we did not include in the model, was more important than any habitat variable we did include. Long-tailed ducks have a strong diving ability (Nilsson 1972) and a diverse diet including epibenthic invertebrates and fish (Robertson and Savard 2002). These characteristics may mean that the long-tailed duck can occupy a broad range of habitat types including deeper water, and therefore may not be as influenced by intertidal shoreline characteristics as other sea duck species.

Other studies of long-tailed duck winter habitat focused primarily on substrate type, and did not agree on one dominant type, which supports the theory that long-tailed ducks can occupy a range of habitat types. Scott and Olson (1973) observed that long-tailed ducks were found in highest abundance along rocky coast headlands and in moderate densities over sandy and rocky ledges in New Hampshire. Nilsson (1972) found the largest numbers of long-tailed ducks over cobble or gravel substrate in southern Sweden.

Alternatively, long-tailed ducks may be associated with habitat features that we did not measure. Further studies could examine the relationship between long-tailed duck winter habitat usage and prey availability.

## **Scoters**

The scoter group was associated with less exposed coastlines and higher numbers of islets. Surf scoters and white-winged scoters made up the majority of the observations during boat surveys, whereas black scoters were much less common.

Vermeer (1981) reported that surf scoters were most commonly found in sheltered waters in southern British Columbia. The diet of surf scoters is primarily bivalves and can include large proportions of mussels (Vermeer 1981). Both white-winged and surf scoters consume clams (Stott and Olson 1973, Lewis et al. 2007).

Goudie et al. (1994) suggested that surf scoters are more numerous over sand and pebble substrates, and Stott and Olson (1973) reported that all species of scoter were more common over sandy substrates on the Atlantic Coast. In a sheltered region of southern British Columbia, Žydelis et al. (2006) found that both surf and white-winged scoters were more abundant in areas with wide intertidal zones, and sandy sediments. Kirk et al. (2008) found that surf scoters occupied both soft bottomed habitats where they consumed clams, and rocky habitats where they consumed mussels.

The habitat selection of scoters appears to be strongly related to their prey selection. Intertidal width and substrate may not have been important

determinants of presence in our results due to a proportion of scoters selecting for wider sandier coastlines and consuming clams, while another proportion was selecting for narrower rockier substrates and consuming mussels.

Less exposure may be preferable due to energetic costs of thermoregulation (McKinney and McWilliams 2005) and foraging in more turbulent water. Less exposure may also be related to the prey species in the case of scoters that may be selecting for clams in wider, sandier coastlines. The association with increased numbers of islets may be due to a relationship between shoreline complexity and islets (complex shoreline may be more likely to have sheltered bays suitable for foraging), or may provide roosting sites free from terrestrial predators.

### **All species groups**

Taken together, the associations we observed form a general picture of habitat that is more commonly associated with sea duck presence (all species together). In 4 species groups, sea ducks were generally more likely to be associated with less exposure of shorelines to high energy waves and in 3 species groups we found birds were in closer proximity to large streams. Thus, we predict that shorelines that are protected from high energy waves and are close to large rivers will support the greatest diversity of sea ducks in Southeast Alaska. It was more difficult to generalize for islets, percent rock, and width parameters. Two groups of sea ducks were associated with larger numbers of islets and rockier shorelines. Width was species specific and was positively

associated with 2 species groups of sea ducks but negatively associated with 1 species group.

## **MANAGEMENT IMPLICATIONS**

This study augments the limited amount of information available on the winter habitat use of sea ducks in Southeast Alaska. The study's broad geographic scope enabled the identification of habitat features that were important over a wide range of possible habitat types. This basic habitat use information is a requirement to advance conservation efforts for sea ducks. The results of this study suggest several types of habitat features that are associated with sea duck presence by species group. While our models could not entirely explain the spatial distributions of the sea duck species groups, our results do suggest certain features that managers could identify during attempts to mitigate the environmental impacts of new development projects or to protect as important habitats.

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