Prey selection and its relationship to habitat and foraging strategy of molting White-winged (*Melanitta fusca*) and Surf Scoters (*M. perspicillata*) in Puget Sound, WA, and the Strait of Georgia, BC.

by

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ABSTRACT

Prey selection and its relationship to habitat and foraging strategy of molting White-winged (*Melanitta fusca*) and Surf Scoters (*M. perspicillata*) in Puget Sound, WA, and the Strait of Georgia, BC.

Heather J. Tschaekofske

This study provides an initial examination of the diet of molting scoters in the Puget Sound, WA, and Strait of Georgia, BC region. Prey species consumption preferences may indicate specific benefits and foraging strategies sought by molting scoters. White-winged (*Melanitta fusca*) and Surf Scoter (*M. perspicillata*) diets differed by location, and major taxonomic prey category. The dominant prey in most prior scoter dietary surveys were bivalves, yet this study found that molting Surf Scoters consumed a significant amount of non-bivalve prey. Additionally, prey size was an important factor relating to habitat, and feeding technique, and small prey (< 5.0mm) were likely consumed in accordance with scoter body size. Molting White-winged Scoters selected a diet of bivalves almost exclusively, primarily mussels (*Mytilus trossulus*) and Varnish clams (*Nuttallia obscurata*). Molting Surf Scoters consumed bivalves primarily at the non-estuarine sites, while selecting for more gastropods, crustaceans, and polychaetes at the estuary sites dominated by eelgrass habitat. The results of this study strongly indicate that selection of smaller non-molluscan invertebrates by Surf Scoters likely relates to their higher organic energy content. I conclude that the greater seasonal availability of diverse prey species during the molting period for scoters allows for increased foraging opportunities.

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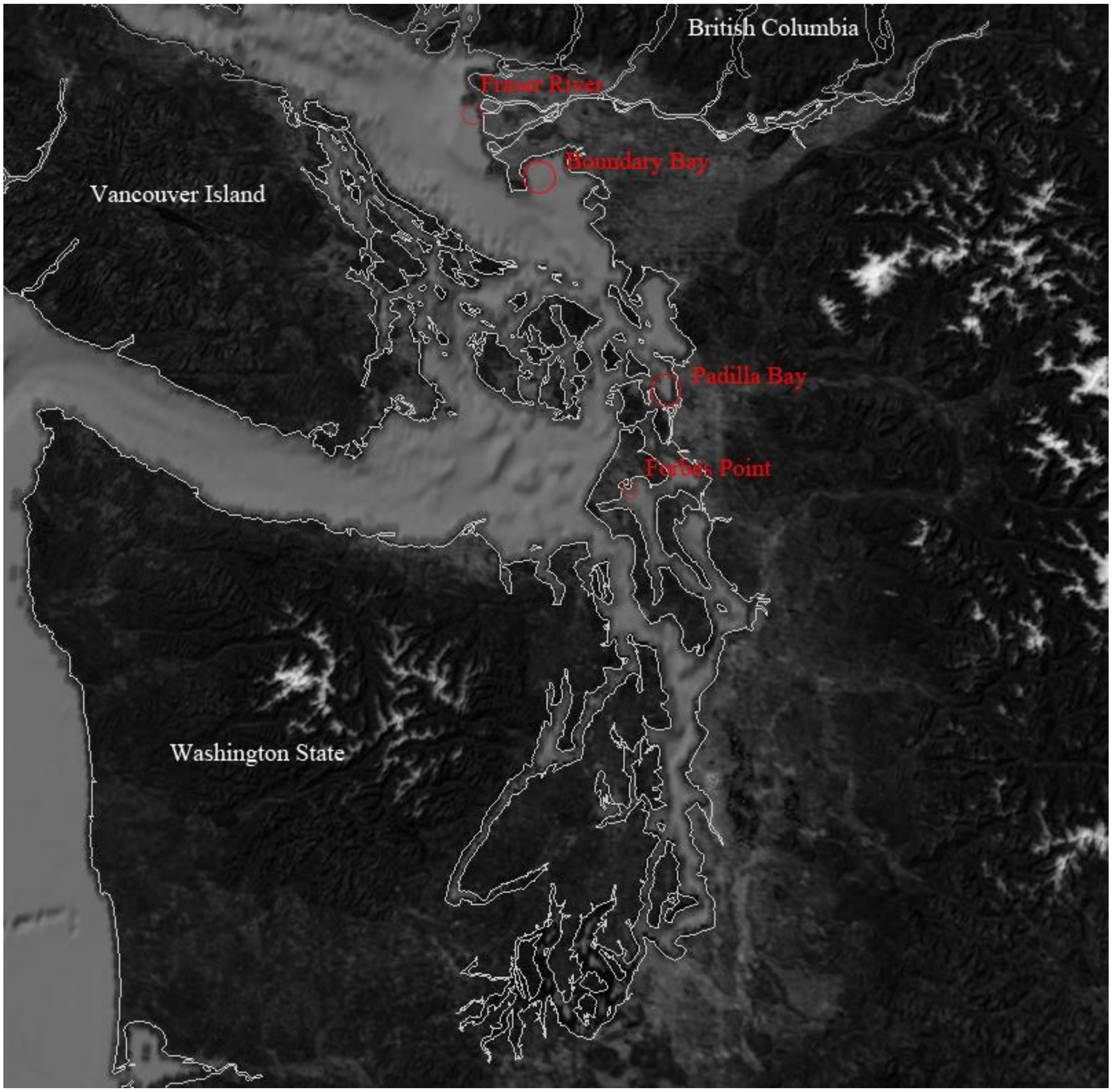
Introduction:

Many seabird species have experienced dramatic declines in the North American region over the last several decades (Hodges et al. 1996, Boersma et al. 2002, Dickson and Gilchrist 2002). Speculation on the causes of decline are variable and diffuse, but may include habitat modification, toxins, overharvest, disease, and invasive species (Boersma et al. 2002, Shumway et al. 2003). Scoter (*Melanitta* spp.) populations in North America have undergone significant declines, in particular along the west coast (Hodges et al. 1996, Dickson and Gilchrist 2002, Nysewander et al. 2005, Bower 2009). Many of the same pressures on seabirds worldwide are experienced by scoter populations in North America, such as habitat changes on the breeding grounds, food stock depletion, contaminants, and hunting pressure (Buchanan 2006). These pressures are exacerbated by low recruitment rates for scoter populations which are dependent on periodic high recruitment rate years and high adult survival to keep population numbers steady (Evenson, J. pers. comm., Krementz et al. 1997). Until recently, most research focused on the nesting biology of scoters, in particular of the White-winged Scoter (*Melanitta fusca*) (Krementz et al. 1997, Savard et al. 1998). Recent investigations have begun untangling the various facets of White-winged and Surf Scoter (*Melanitta perspicillata*) ecology outside the breeding season. Much of this recent research has focused on winter and spring foraging, as well as scoter prebreeding migratory behavior (Lewis et al. 2005, Žydelis et al. 2006, Lewis et al. 2007a, Kirk et al. 2007, Kirk et al. 2008, Lewis et al. 2008, Anderson et al. 2009b, De La Cruz et al. 2009, Žydelis et al. 2009). The postreproductive molting ecology of scoters has received very little attention until recently (Evenson, J. unpubl. data, Savard et al. 2007, Dickson et al. 2010).

Sea duck (Mergini) species undergo a simultaneous molt in which all flight feathers are replaced, resulting in a flightless period typically ranging from 4 – 7 weeks during the summer and fall (Salomonsen1968, Jehl 1990, Hohman et al. 1992, Guillemette et al. 2007). This results in a molting period that is compressed in time, and energetically demanding. For example, Common Eiders (*Somateria mollissima*) are flightless for an average of 36 days during late summer (Guillemette et al. 2007). White-winged and Surf Scoters are also typically flightless for four weeks approximately (Anderson, E., pers. comm.). Scoters must compensate for their restricted movement during the molting period by seeking out molting locations that provide predictable food resources, as well as adequate predator protection (Salomonsen 1968, Storer and Jehl 1985, Hohman et al. 1992, Murphy 1996). Many scoters undergo an annual post breeding molt migration from interior taiga/tundra breeding grounds to traditional sites in saltwater habitats along the pathway to wintering grounds, with the exception of most female White-winged and some female Surf Scoters that molt near the breeding grounds (Salomonsen 1968, Johnson and Richardson 1982, Herter et al. 1989, Hohman et al. 1992, Savard et al. 2007). Many of these sites are remote and have been poorly documented up until recently (Johnson and Richardson 1982, Herter et al. 1989, Brown and Fredrickson 1997, Savard et al. 1998). In the Pacific Northwest, Surf and White-winged Scoters have been documented at molting locations in Northern Puget Sound and the Southern Strait of Georgia (Savard 1988, Nysewander et al. 2005). From this region, this study will focus on the following four sites: Boundary Bay, Padilla Bay, Forbes Point and the Fraser River delta (Figure 1).

Figure 1. Study site locations for molting White-winged and Surf Scoters in Puget Sound, WA, and Strait of Georgia, BC.



Prior studies of the molting ecology of ducks and geese primarily focused on daily energy expenditures, and whether birds compensate for the high energy demands during the molting period with changes in behavior or physiology (Ankney 1979, Sjöberg 1988, Thompson and Drobney 1997, Brown and Saunders 1998, Adams et al. 2000, Guillemette et al. 2007). Few studies have directly examined diet composition during molt for ducks and geese (Hohman et al. 1992, Thompson and Drobney 1997, Rodway and Cooke 2002), and only one east coast study specifically examined scoter diets during the molting period (Budge and Gilliland 2007). The high number of scoters that congregate at saltwater molting locations indicates that these habitats are extremely valuable, and require further study (Herter et al. 1989, Brown and Fredrickson 1997, Savard et al. 1998, Savard et al. 2007). At a single molting site such as Padilla Bay where breeding age female Surf Scoters are dominant, future environmental impacts could have dramatic effects on Surf Scoter populations.

Diving ducks, such as scoters, have high daily energy expenditures related to diving activities, and thermoregulation in cold-water environments (Nilsson 1972, Goudie and Ankney 1986). When molting, these energy needs increase not only to provide adequate protein synthesis for feather growth, but also to compensate for reduced thermoregulatory and diving abilities with the loss of flight feathers (Hohman et al. 1992). There appears to be varied species responses to the demands of molt, as some species select food items higher in protein content, while other species vary their behaviors to offset the nutritional demands during molt (Hohman et al. 1992, Adams et al. 2000, Guillemette et al. 2007, Dickson et al. 2010). Larger species have lower energy demands per unit body mass, which allow for more flexible foraging strategies, while smaller species are more susceptible to the increased nutritional costs during molt and may suffer greater stress (Baker and Baker 1973, Hohman et al. 1992). Surf Scoters may be subjected to greater nutritional demands as they are much smaller than White-winged Scoters. Additionally, some molting ducks forage less and lose body mass over the course of the molting period (Sjöberg 1988, Adams et al. 2000, Guillemette et al. 2007).

This occurs presumably as an adaptation for a quicker return to flight, as a lighter bird is able to fly before all feathers re-grow to maximum remigial length (Sjöberg 1988, Hohman et al. 1992, Brown and Saunders 1998).

Studies of scoter foraging ecology have primarily been conducted during the winter and spring seasons (Grosz and Yocom 1972, Sanger and Jones 1982, Vermeer and Bourne 1984, Hirsch 1980, Ryder 2007, Kirk et al. 2007, 2008, Lewis et al. 2007a, 2007b, 2008). Previous studies in North America documented the predominance of bivalve species in both Surf and White-winged Scoter diets (Grosz and Yocum 1972, Stott and Olsen 1973, Vermeer and Levings 1977, Hirsch 1980, Bourne 1984, Vermeer 1981, Lewis et al. 2007a). However, a number of studies from the Pacific Northwest have illuminated greater variability in scoter diets, with alternative prey such as herring roe, and soft bodied organisms showing increasing importance (Hirsch 1980, Lacroix et al. 2005, Lewis et al. 2007b, Anderson et al. 2008, Anderson et al. 2009b). In some cases, this variance may be related to sampling methodology and collection techniques rather than regional or temporal differences (Anderson et al. 2008). Regardless, the importance of non-bivalve prey items to scoters has been understated. Specifically, several studies show Surf Scoter diets diverge from a bivalve dominated diet more often than White-winged Scoters (Hirsch 1980, Anderson et al. 2008).

Many prior scoter dietary studies employed lethal methodologies in order to evaluate the food items contained in the esophagus and/or gizzard of each bird (Grosz and Yocom 1972, Stott and Olson 1973, Hirsch 1980, Sanger and Jones 1982, Vermeer and Bourne 1984, Lovvorn and Baldwin 1996, Anderson et al. 2008). There is some potential for differential retention of soft parts versus hard parts depending on whether the esophagus or gizzard contents are analyzed, or whether the study took place in freshwater versus saltwater (Swanson and Bartonek 1970, Stott and Olson 1973, Anderson et al. 2008). Depending on how quickly samples are processed, there can be varying degrees of digestion that occur in gastro-intestinal samples. However, the ability to measure and weigh whole prey items is much more plausible with a lethal methodology, versus fecal analysis. Despite the absence of volumetric information, fecal analysis provides an appropriate snapshot of what the bird has recently consumed (Robert and Cloutier 2001, Rodway and Cooke 2002). Fecal sample collection is a non-lethal methodology that can yield large sample numbers, and does not negatively affect population numbers for scoter species which are already in decline. The drawback with utilizing fecal samples rather than intact gastro-intestinal samples is that prey break down more completely, and soft parts may not be easily identifiable in fecal samples. This is a debatable issue, and there is research utilizing both methodologies within the field of sea duck dietary research.

The primary objective for this study was to determine to the finest level of detail what prey species were being consumed by White-winged and Surf Scoters at the four selected molting locations. This was done with a non-invasive methodology utilizing fecal samples, and the final results of this study will be compared to prior dietary studies that have primarily used gastro-intestinal samples. Comparative analysis between the four molting locations, as well as between the two scoter species may indicate specific preferences during the molting period. Final results will provide insight into the variable nutritional benefits related to selected prey consumed by White-winged and Surf Scoters.

Methods:

Study Area:

This study was conducted in the Northern Puget Sound, and Southern Strait of Georgia region at the following four locations: Padilla Bay, Boundary Bay, Fraser River delta, and Forbes Point (Figure 1). Two of the sites, Padilla Bay, and Boundary Bay, represent some of the largest estuary seagrass habitat on the Pacific coast of North America, with 3200, and 5600 hectares of seagrass respectively (Bulthuis 1995, Lovvorn and Baldwin 1996). Padilla Bay (48°30’N, 122°30’W) is located east of the San Juan Islands, and is primarily intertidal with sandy substrates, with eelgrass (*Zostera marina*) beds comprising the dominant habitat (Ray 1997). Padilla Bay is significantly smaller than Boundary Bay, yet eelgrass densities are much greater in Padilla Bay. Molting Surf Scoters were found primarily in the southern portion of Padilla Bay, where freshwater influences are greatest. Boundary Bay (49°N, 123°1W), situated on the border between British Columbia and Washington State, is characterized by extensive intertidal mudflats and eelgrass beds. White-winged Scoters were most frequently found in the shallower waters of Boundary Bay where eelgrass was sparse, and the substrates were sand/mud. Surf Scoters primarily occupied the deeper waters at this site, with a thin transition zone between deep and shallow waters in which both scoter species overlapped. The Fraser River delta (49°7’N, 123°11W) also has a vast expanse of shallow intertidal mudflats that are adjacent to Boundary Bay. The Fraser River delta is also estuarine in nature, yet the large freshwater influence at this site prevents eelgrass from developing, differentiating it from the two former estuarine sites dominated by eelgrass habitat. Scoters were captured primarily between Sturgeon Bank and Roberts Bank north of the middle arm of the Fraser River delta. White-winged and Surf Scoters were primarily found in mixed flocks on the

Fraser River delta, with White-winged occasionally occupying shallower waters. Forbes Point (48°27'N, 122°62'W) separates Oak Harbor and Crescent Bay at the northern end of Saratoga Passage, and is situated on the northwestern shore of Whidbey Island in Northern Puget Sound. Forbes Point is characterized by rocky reefs, and sandy substrates adjacent to the reef outcroppings. Aquacultural activities in the nearby Penn Cove area have influenced the bivalve composition near Forbes Point, with abundant mussels growing on the sandy bottom as well as the rock outcroppings. Boundary Bay and the Fraser River delta are within the Western Hemisphere Shorebird Reserve Network, while Padilla Bay is a National Estuarine Research Reserve. Each of these designations verifies the importance of the bird and estuarine habitats at these scoter molting locations.

Fecal Sample Analysis:

Fecal samples were obtained from Surf and White-winged Scoters captured during a Washington Department of Fish and Wildlife (WDFW) banding project from July, August, and September 2009. (Breault and Cheng 1990, Paton et al. 1991, Kaiser et al. 1995, Gilchrist and Heise 1997) WDFW began banding scoters at the study sites in 2007 to ascertain the molting demographics for these two species that have declined on the west coast. The approximate age of each banded bird was determined through bursal depth (Iverson et al. 2003), and various morphometric measurements such as 9th primary length, culmen length, and body mass were also taken. Mass was used as a metric to characterize the overall health of each bird.

Scoters were selected for fecal collection by securing the first 2-3 extracted birds from each net set, and placed in plastic lined small animal crates. The other birds captured in the set were placed in mesh bags, and then all birds were transported to a larger processing vessel. Up to 8 of the bagged birds were placed in plastic lined small animal crates on the processing boat, and all birds in the lined crates were processed last to allow time for defecation. After all birds were released, the plastic liners that contained fecal material were collected, bagged, kept in coolers, and then frozen at the close of each field day for later analysis.

Sample identification began when samples were thawed, rinsed with water, and examined under a dissecting microscope (10x power). Several test runs were conducted sieving fecal samples with 500 μm mesh, and it was determined that important fragments, such as worm setae, were lost in the sieving process. Prey fragments were identified to the lowest taxonomic level possible by examining gross physical characteristics such as interior and exterior shell color, texture, hinge structure, size, and presence of intact appendages or body structures for non-molluscan prey. Where there were discernable features, such as complete head parts or intact shells, individual prey species were counted. Prey identification was facilitated by taxonomic keys (Griffith 1967, Kozloff 1987), as well as with qualitative reference samples collected from each of the study sites during the same time period. These qualitative collections were categorized and stored in 70% isopropyl alcohol. Expert marine taxonomists were consulted for questionable samples (Thuesen, E., pers. comm.; Pacific Shellfish Research Institute). Each fecal sample represents a random sample unit, from an individual bird, and there were no repeat samples taken. Samples were variable in the amount of fecal content, since some birds may have defecated during the capture and handling process. Scoters placed immediately in small animal crates after each net set would likely have more fecal material present than those birds placed in mesh bags prior to placement in the small animal crates. Therefore, it was not possible to compare volumetric content between samples. In addition, almost all hard prey items were broken down into fragments approximately 5- 10 mm across, thus complete prey size was nearly impossible to ascertain. For each individual fecal sample, prey presence was noted, and intact prey were measured and counted. After identification, samples were preserved in 70% isopropyl alcohol.

Statistical Analysis:

For descriptive statistical analysis, average number of species present, standard deviation, frequency of occurrence, and Shannon-Wiener diversity indices were calculated for all the prey species present at the four sites. Only major prey categories (MPC) (bivalvia, gastropoda, crustacea, and polychaeta) , were utilized for ordination and hypothesis testing, to rule out potential site specific environmental differences unrelated to scoter dietary choices. For example, Varnish clams (*Nuttallia obscurata*) may be abundant at one site, yet absent at another because of habitat differences, yet the choice of an alternative bivalve species would indicate a similar scoter dietary preference. Nonparametric statistical analyses were conducted on the MPC using PC-ORD (5.10) software. Non-metric multidimensional scaling (NMS) ordination was performed to graphically summarize the environmental patterns in the dataset, and thus the potential similarity or dissimilarity between sample units (individual fecal samples) (see Appendix A for description of NMS procedure). Since this study contains data that relate to a non-normal scale, defined by scoter dietary preferences rather than prey availability, NMS ordination was chosen because it avoids the assumption of linear relationships between variables while using rank ordering to identify similarity between data points (Clarke 1993, McCune and Grace 2002). Multi-response Permutation Procedure (MRPP) was utilized for significance testing ($p < 0.05$) of MPC differences based on location, and scoter species, sex, and age. MRPP is also robust to datasets that exhibit nonlinear relationships and is commonly used for ecological community datasets (Biondini et al. 1985, McCune and Grace 2002). Sørensen (Bray-Curtis) distance measures were used for all MRPP calculations, to match the recommended settings for NMS analysis (McCune and Grace 2002). Refer to Appendix B for a detailed description of MRPP functions. Specific statistical differences in MPC consumption for Surf and White-winged Scoters at all four molting locations were determined with Fisher's exact test using R (2.11.0) software.

NMS is especially suited to the unique characteristics of community ecology datasets which contain considerable zero values denoting species absence (McCune and Grace 2002). However, overall comparisons between all four molting locations, and both scoter species combined required a specific transformation to compensate for the abundance of zero values within the total dataset. Beals smoothing is a multivariate transformation which replaces all values in the dataset with new values based on the probability of occurrence relative to co-occurring species in the dataset (McCune 1994, McCune and Grace 2002, De Cáceres and Legendre 2008). Smoothing the dataset helps make underlying patterns more evident, especially when dealing with an abundance of samples that have few species. Beals smoothing was performed only for the NMS ordination of both scoter species combined at all four molting locations. These results revealed significant patterns in the dataset, but were unduly influenced by Surf Scoters at

Padilla Bay, thus ultimately each species was assessed separately. Subsequent analysis of individual scoter species did not require Beals smoothing, and the remaining datasets were rank-transformed. Rank-transformation involves conversion of the dataset distance measures to ranks (see Appendix C for transformation procedures). This procedure tends to produce results most closely aligned with those obtained from NMS ordination (McCune and Grace 2002).

Results:

Ten samples from the 153 collected had no prey items present in the fecal sample. From the 143 remaining (Table 1), there were 19 total prey items found in fecal samples from all of the molting locations combined (Appendix D for total prey samples/site). Most prey items found were identified to the family or species level. The two estuary sites averaged more prey per sample, with 2.5 prey/sample (SD ± 1.7, n = 26) for Boundary Bay, and 2.9 prey/sample (SD ± 1.4, n = 51) for Padilla Bay. Forbes Point averaged 1.4 prey/sample (SD ± 0.6, n = 20), and the Fraser River averaged 1.4 prey/sample (SD ± 0.8, n = 46). The Shannon-Wiener index was calculated to determine which of the four locations had greater prey diversity relative to the proportion of prey present. Prey diversity followed a similar trend at the two estuary sites, with higher diversity indices (H') of 2.36 and 2.38 respectively for Boundary Bay and Padilla Bay. The Forbes Point and Fraser River sites had lower H' values of 0.94, and 1.15 respectively. The lower diversity values are not unexpected when looking at the frequency of occurrence for prey consumed at these two sites, which were both dominated by a single bivalve species (Table 2).

Table 1. Summary statistics for scoter samples collected at molting sites.

	WWSC			SUSC			
Location	Female	Male	Total	Female	Male	Total	All Scoters
Boundary Bay	1	13	14	9	3	12	26
Forbes Point	2	3	5	7	8	15	20
Fraser River	9	19	28	8	10	18	46
Padilla Bay	0	0	0	48	3	51	51
All Locations	12	35	47	72	24	96	143

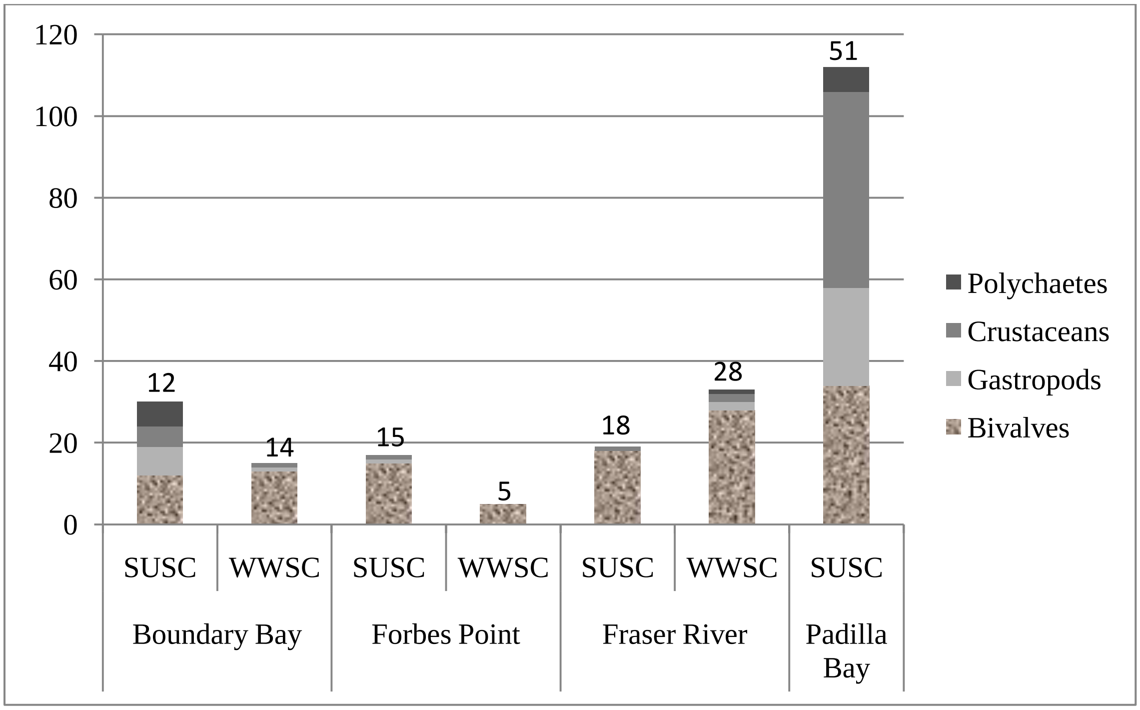
Table 2. Frequency of occurrence for prey items identified from Surf and White-winged Scoter fecal samples at four molting locations in Northern Puget Sound, and Southern Strait of Georgia, with sample totals in parenthesis (F = female, M = male).

	Boundary Bay		Forbes Point		Fraser River		Padilla Bay
	SUSC	WWSC	SUSC	WWSC	SUSC	WWSC	SUSC
	(9F, 3M)	(1F, 13M)	(7F, 8M)	(2F, 3M)	(8F, 10M)	(9F, 19M)	(48F, 3M)
	FO%	FO%	FO%	FO%	FO%	FO%	FO%
Bivalvia	**100**	**93**	**100**	**100**	**100**	**100**	**67**
Mytilidae (Mytilus trossulus)	25	7	100	100	17	4	25
Cardiidae	92	14	-	40	-	-	4
Macoma balthica	-	-	-	-	11	-	-
Macoma sp.	8	-	-	-	-	-	2
Psammobiidae (Nuttallia obscurata)	8	57	20	20	100	100	35
Veneridae	58	14	-	-	17	4	6
Unidentified Bivalvia	17	7	-	-	-	-	14
Gastropoda	**58**	**7**	**7**	**-**	**-**	**7**	**47**
Pyramidellidae	-	-	-	-	-	-	16
Potamididae (Batillaria atramentaria)	-	7	-	-	-	-	2
Unidentified Gastropoda	58	-	7	-	-	7	35
Crustacea	**42**	**7**	**7**	**-**	**6**	**7**	**94**
Idoteidae	25	-	-	-	-	7	41
Cancridae	8	7	-	-	-	-	4
Pinnotheridae	-	-	-	-	-	-	67
Caprellidea (Caprella sp.)	-	-	-	-	-	-	4
Unidentified Crustacean	8	-	-	-	6	-	8
Amphipoda	17	-	7	-	-	-	-
Echinodermata (Ophiuroidea)	-	-	-	-	-	-	4
Polychaeta	**50**	**-**	**-**	**-**	**-**	**4**	**12**
Plant material	17	14	-	-	-	7	12

Overall, White-winged Scoters were more reliant on bivalves than Surf Scoters, with 98% frequency of occurrence for bivalve prey species (Appendix D). Of these, the Varnish clam was the most frequent bivalve species, found in 79% of White-winged Scoter samples. Varnish clams have been determined to be an important food and habitat attribute for both scoter species at other locations in the Strait of Georgia (Žydelis et al. 2006, Kirk et al. 2007, Lewis et al. 2007a, 2008). Additionally, mussels (*Mytilus trossulus*) and cockles (Cardiidae family, *Clinocardium* spp.) occurred in 15%, and 9% of all White-winged Scoter fecal samples, respectively. A small percentage of non-bivalve prey species were eaten by White-winged Scoters at the Boundary Bay and Fraser River sites. Of these, gastropods, and crustaceans occurred with 6% frequency, while polychaetes were found in 2% of samples.

Bivalves also comprised a large percentage of prey consumed by Surf Scoters, with 82% frequency of occurrence in samples from all molting locations (Appendix D). Of these, the most frequent were Varnish clams, with 42% occurrence, followed by mussels with 35% occurrence. Veneridae (likely *Transennella* spp.), and cockles were both found in 14% of samples. Non-bivalve prey species were present in Surf Scoter fecal samples with a much higher frequency of occurrence than in White-winged Scoters, with gastropods in 33% of samples, crustaceans in 57%, and polychaetes in 13%. Over half of the Surf Scoter samples were from the Padilla Bay site, which contributed the greatest proportion of non-bivalve related prey samples (Figure 2). Removing the Padilla Bay samples from analysis still results in higher Surf Scoter consumption of non-bivalve prey than White-winged Scoters, with gastropods in 18% of samples, crustaceans in 16%, and polychaetes in 13%.

Figure 2. Number of scoter samples with MPC /site (total samples above bar).



Pooled scoter sample analysis between molting sites revealed site specific variations in prey consumption. Geographically, there were significant differences amongst the four molting locations (T = -38.24, A = 0.48, $p < 0.00$) in scoter consumption of MPC items. The test statistic T reflects the difference between the grouping variables. Larger negative T values indicate stronger separations between groups.

$$T = (\text{observed } \delta - \text{expected } \delta) / \text{ standard dev. of expected } \delta$$

The distribution of δ (weighted mean within-group distance) describes whether or not prey items are randomly defined by the grouping variables. The probability that this result is greater than what is expected by chance is determined with Pearson type III distribution analysis (Biondini et al. 1985, McCune and Grace 2002). Smaller δ values indicate tighter within group clustering, while larger values indicate a more dispersed arrangement. Finally, the *A* statistic describes the chance-corrected within-group agreement, or the effect size (McCune and Grace 2002). An *A* value equal to one would indicate absolute within-group homogeneity, with the observed δ equal to the expected δ. An *A* value equal to zero indicates that heterogeneity within groups is due to chance. Values of *A* greater than 0.3 can be considered fairly large in the context of community ecology studies (McCune and Grace 2002).

Larger average within-group distances at Boundary Bay and Padilla Bay (δ = 0.14, and 0.10 respectively) indicate greater within-group variation, while the Forbes Point and Fraser River sites (δ = 0.04, and 0.04 respectively) tend to be more clustered. This likely reflects the greater prey diversity at the two estuary sites dominated by eelgrass habitat. Pair-wise comparisons between all four molting locations revealed significant differences between all sites, with the exception that prey consumption between Forbes Point and the Fraser River sites was similar for both scoter species (*T* = 0.97, *A* = -0.01, *p* = 1.0) (Table 3). The greatest differences found in MPC consumption were found when Padilla Bay was compared to the other three molting locations, indicating the unique nature of this site.

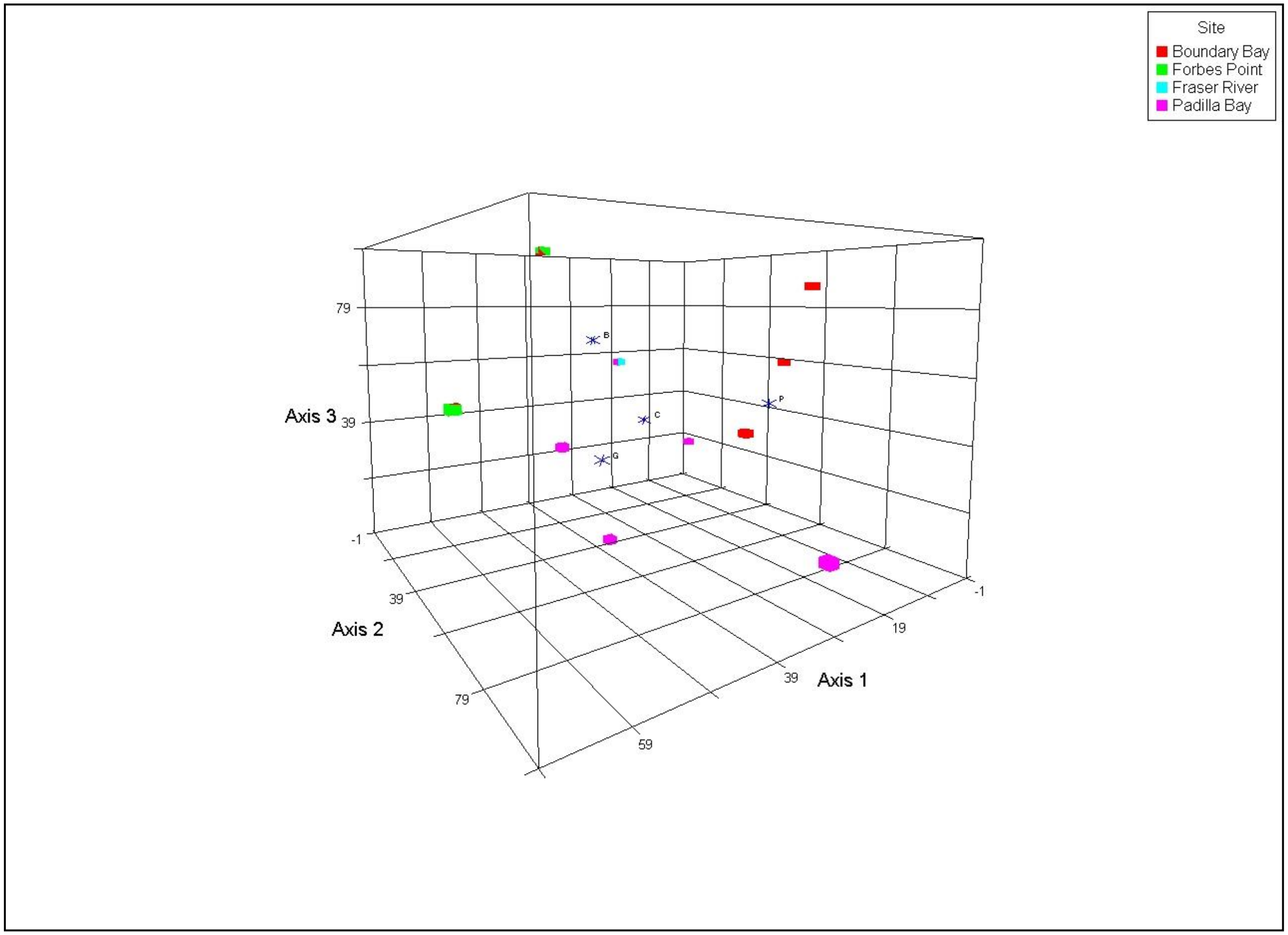
Table 3. MRPP summary statistics for pair-wise comparisons of MPC consumption at the four molting locations (rank-transformed data).

	T	*A*	*p*
Boundary Bay vs. Forbes Point	-4.73	0.11	0.00
Boundary Bay vs. Fraser River	-8.01	0.11	0.00
Boundary Bay vs. Padilla Bay	-22.00	0.22	0.00
Forbes Point vs. Fraser River	0.97	-0.01	1.00
Forbes Point vs. Padilla Bay	-38.22	0.47	0.00
Fraser River vs. Padilla Bay	-54.57	0.57	0.00

Of the three locations with both scoter species present, significant differences existed between White-winged and Surf Scoter diets at Boundary Bay (T = -8.80, A = 0.31, p < 0.00), where Surf Scoters consumed more gastropods (p = 0.009, two-sided Fisher's exact test), and polychaetes (p = 0.004, two-sided Fisher's exact test). At the remaining two sites with both scoter species present the difference between White-winged and Surf Scoter MPC consumption was not significant (Forbes Point, T = -0.33, A = 0.01, p = 0.27) (Fraser River, T = 0.26, A = -0.00, p = 0.49).

Individual analysis of scoter diets at the four molting locations indicated specific dietary preferences for Surf Scoters. NMS Ordination analysis revealed significant (p = 0.02) patterns in three-dimension space for Surf Scoter consumption of MPC at the four molting sites (Figure 3). Ordination results for White-winged Scoters were inconclusive, largely because of the overwhelming influence of bivalve prey.

Figure 3. Results of NMS ordination in three-dimensional space, showing MPC by location for Surf Scoter samples (MPC symbols abbreviated: B, G, C, P).



MRPP analysis displayed similar trends in Surf Scoter consumption of MPC, with significant differences amongst the four sites (T = -27.04, A = 0.43, p = 0.00). However, there was no significant difference between Surf Scoter consumption of MPC at Forbes Point and the Fraser River (T = 0.75, A = -0.02, p = 0.76). Male and female Surf Scoters had significant differences in consumption of MPC across molting locations (T = -14.02, A = 0.13, p = 0.00), specifically females ate more crustaceans ($p < 0.00$, two-sided Fisher's exact test). There were no differences in prey consumption by Surf Scoter age classes. White-winged Scoters ate bivalves almost exclusively, thus there were no significant differences in MPC consumption by sex, age, or location.

Discussion:

This study presents some of the first findings regarding the diet specific to the molting period for Surf and White-winged Scoters in the Puget Sound, WA, and Strait of Georgia, BC region. These findings may contribute to the broader investigation of scoter declines in North America. By identifying critical habitat, and food resources, future management of scoter resources can be appropriately directed. In general, White-winged and Surf Scoters consumed a high proportion of bivalves at each of the study sites, with the exception of Padilla Bay, where non-bivalve species were more prevalent for Surf Scoters. Since the majority of Surf Scoters at Padilla Bay are breeding age females, consumption of non-bivalve related prey in higher frequencies is noteworthy. At the two estuary sites with eelgrass habitat, frequency of non-bivalve prey items rivaled bivalve occurrence. Despite best efforts, these findings likely underestimate the proportion of non-bivalve species since the amount of soft material that is retained in fecal samples is lower than that obtained from gastro-intestinal sampling. Regardless, the specific bivalve and non-bivalve prey that were consumed during the molting period undoubtedly relate to specific nutritional and behavioral needs for each scoter species during this demanding life stage.

Bivalve Consumption by Molting Scoters:

Prior scoter dietary studies emphasized the importance of bivalve species, particularly Manila clams (*Venerupis philippinarum*), Littleneck clams (*Protothaca staminea*), mussels, and Varnish clams in the Pacific Northwest (Vermeer and Levings 1977, Vermeer 1981, Vermeer and Bourne 1982, Bourne 1984, Ryder 2007, Žydelis et al. 2006, Lewis et al. 2007a, 2008). Interestingly, there were no adult Manila or Littleneck clams present in any of the fecal samples, as almost all the Veneridae family prey items were most likely *Transennella* species. One possible juvenile Manila clam was found with the potential *Transennella* clams in a sample from Boundary Bay, and can be visually compared in the photograph in Figure 4. *Transennella tantilla* clams were found to be widespread throughout Padilla Bay habitats in a 1994 survey of the bay (Ray 1997). These clams live on the surface of the sediments, generally not exceeding 5.0 mm in length. The Veneridae bivalves consumed in this study were < 4.0 mm in size, and often densely aggregated within samples. The small size of the Veneridae bivalves overall suggests that scoters were likely siphon or suction feeding these bivalves from the sandy sediments at the two estuary sites, as well as the Fraser River delta. Siphon feeding has been found to be an efficient foraging strategy for sea ducks consuming small high energy prey items, such as herring roe and small bivalve species (Sanger and Jones 1982, De Leeuw and Van Eerden 1992, Lewis et al. 2007b). The soft sediments of the estuary sites may also provide opportunities for consumption of other non-bivalve species in a similar manner.

Figure 4. Photograph taken through dissecting microscope (10x power) of two Veneridae clams, with likely *Transennella* species on the right, and possible Manila clam on the left (several small gastropod species also pictured). Clams pictured < 3.0 mm in width (see Appendix E for additional picture with mm calipers shown).

Of the larger bivalves consumed, Varnish clams and mussels dominated both Surf and White-winged Scoter diets, with the exception of the *Cardiidae* species present in Surf Scoter samples from Boundary Bay. Seasonal differences in mussel size and availability often dictate consumption by scoters, and other sea duck species (Zwarts and Wanink 1993, Bustnes 1998, Guillemette 1998, Kirk et al. 2007, 2008). Kirk et al. (2008) found that seasonal depletion of mussels likely affected scoter movements later in the winter. Many bivalve species are more abundant in the summer and fall, thus scoters may not be limited by prey availability during the molting period as much as they would during the winter (Zwarts and Wanink 1993). Various studies have inferred differential energy gains from the consumption of mussels versus clams (Zwarts and Wanink 1993, Bustnes 1998, Richman and Lovvorn 2003). In many instances, mussels are more efficiently acquired, since they are not buried within the sediment and are often found visibly anchored in dense clusters. However, the greater energy content of larger clams such as Manila and Varnish clams offsets some of the expense from searching in sediments (Kirk et al. 2007). Smaller mussels have higher organic energy content, and less shell than larger mussels proportionally (Bustnes 1998). Mussels have historically been an important prey item for both scoter species at the Fraser River delta, occurring in 19% of White-winged Scoter samples taken during the summer of 1974, and constituting the primary prey in Surf Scoter samples annually from 1974 – 1977 (Vermeer and Levings 1977, Vermeer 1981, Vermeer and Bourne 1982). The dependence on mussels may be changing as the recent appearance and dominance of the Varnish clam in scoter samples from this region would indicate.

Since the accidental introduction of the Varnish clam in the late 1980's in British Columbia waters, it has rapidly expanded throughout the Strait of Georgia and Puget Sound (Gillespie et al. 1999). Recent studies of wintering scoters in this region have found that both Varnish and Manila clams dominate Surf and White-winged Scoter diets (Žydelis et al. 2006, Lewis et al. 2007a, Lewis et al. 2008). Varnish clams were found to be a significant determinant for predicting scoter densities in the Baynes Sound, Strait of Georgia region (Žydelis et al. 2006). Their presence and the absence of the more regularly encountered Manila and Native Littleneck clams from molting scoter fecal samples is noteworthy when comparing prior scoter dietary studies. All three of these bivalve species can be found at the four molting sites throughout the year (Vermeer and Levings 1977, Vermeer and Bourne 1982, Vermeer 1981, Dinnel 2000), yet scoters appear to be selecting Varnish clams during the molting period. In general, Varnish clams are more freshwater tolerant, and situate higher in the intertidal zone, and tend to be located at similar or slightly deeper substrate depths when they co-occur with Manila clams (Gillespie et al. 1999). Varnish shells are thinner than Manila clams, yet they contain greater flesh ratios (Gillespie et al. 1999), making them an attractive prey alternative for scoters. Additionally, it appears that this relatively new invasive species may be linked to the recent appearance of substantial molting scoters at the Fraser River during the summer. Coastal molting sea duck surveys had documented very few scoters utilizing the Fraser River during the molting period prior to 1986 (Savard 1988). Currently, approximately 10,000 or more molting scoters utilize the Fraser River (Evenson, J., pers. comm.).

There have been other instances of ducks altering migratory behaviors to congregate in dense flocks where invasive prey species have recently become prolific. Specifically, Greater (*Aythya marila*) and Lesser Scaup (*A. affinis*) altered their diets in the Great Lakes after the accidental introduction of the Zebra Mussel (*Dreissena polymorpha* and *D. bugensis*), as well as in the San Francisco Bay area where the Asian clam (*Corbula amurensis*) is now a favored prey species (Wormington and Leach 1992, Petrie and Knapton 1999, Poulton et al. 2002). Invasive clam species such as the Zebra mussel and Asian clam have been found to accumulate toxins at greater levels than other native bivalve species (Hoffman et al. 1998, Petrie and Schummer 2002). The Zebra mussel has prolific filtering capabilities that differ from the Varnish clam, yet Varnish clams feed through both filter and deposit feeding mechanisms (Gillespie et al. 1999), which may also permit greater toxin accumulation (Meacham 2010). The non-native Manila clam has been studied in relation to Varnish clams in light of their similar commercial benefits. Experimental treatments between Varnish and Manila clams show that they tend to negatively affect each other when both are present in the same area (Gillespie et al. 2001).

The Varnish clam has been proposed as a commercial clam species, yet there has been little toxicological testing of contaminant or marine toxin accumulation with this species to date. Testing done off Vancouver Island in September and October of 1998 by the Northwest Fisheries Science Center division of the National Oceanic and Atmospheric Administration, found Varnish clams accumulated slightly higher levels of PSP toxin than Manila clams and oysters (NOAA-Northwest Fisheries Science Center 1998). They were tested twice during the fall season, and consistently retained higher toxin levels than Manila clams. These levels were below the toxic indicator threshold for human consumption, yet this may indicate higher retention of toxins in general for the Varnish clam species. Gillespie et al. (1999) cited limited testing done by the Canadian Food Inspection Agency in 1998 which found similar levels of toxicity between Varnish clams and Manila clams. Without further testing, it is impossible to say whether there is any concern for biomagnification of toxins in scoters from consuming large quantities of Varnish clams. Despite this, scoters are certainly exposed to industrial and agricultural contaminants that runoff from the Vancouver metropolitan and Fraser valley areas into the Fraser River. In addition, the Vancouver International Airport is situated at the north end of the Fraser delta near molting scoters, along with major shipping and coal industries. Future research could compare the toxicity of molting scoters in these industrial areas to those that molt on the outer coast at sites without urban influences, as well as the toxicity of scoters present on the Fraser River year round. The relationship between Varnish clams, and Surf and White-winged Scoters in the Pacific Northwest deserves further scrutiny.

Non-Bivalve Prey Consumption by Molting Scoters and Prey Size Selection:

Molting Surf Scoters in this study consumed a greater variety of non-bivalve prey items than White-winged Scoters. Consumption of gastropods, crustaceans, and polychaetes was greatest at the two estuary sites with eelgrass habitat, highlighting the importance of this habitat as it provides a diversity of epifaunal invertebrate prey. Surf Scoters at Boundary Bay fed most frequently near eelgrass (*Zostera marina*) habitat compared to White-winged Scoters, and this is evident when examining the significant difference in prey species consumption from this site. Specifically, isopods and pinnotheridae crabs were most frequently found in Surf Scoter fecal samples from Boundary Bay and Padilla Bay. Two frequently encountered isopod species are the Rockweed (*Idotea wosnesenskii*) and Eelgrass Isopod (*Idotea resecata*), commonly found under rocks and amongst seagrasses. Isopod fragments in fecal samples were too small to clearly identify to species. Pinnotheridae crabs are generally found commensally within other invertebrates, most frequently in bivalves, or inside worm tubes. The pea crab *Pinnixa tubicola* is the most commonly encountered pinnotheridae crab in sheltered waters along the west coast, such as at Padilla Bay (Ricketts and Calvin 1978, Ray 1997, Riggs 2003). *P. tubicola* resides within worm tubes, generally of terebellid polychaete species. At Padilla Bay, these crabs have been found in *Ulva* spp. and *Z. marina* dominated habitats, ranging from shallow to subtidal depths (Ray 1997). Riggs (2003) documented *P. tubicola* ranging in size from 3.1 to 7.1 mm in above-ground traps at Padilla Bay. In this study, Pinnotheridae crab fragments found in Surf Scoter fecal samples from Padilla Bay were generally < 5.0 mm in size, and quite numerous in a number of samples. Since this crab species resides in worm tubes, it is possible that Surf Scoters were grabbing clumps of sediment in order to obtain worm and crab prey.

Another common pinnotheridae crab species that can be found in the Puget Sound region is *Fabia subquadrata*, otherwise known as the mussel pea crab. They are primarily commensal in mussels, but may inhabit other bivalves periodically (Pearce 1966, Ricketts and Calvin 1978), and have recently been found in Varnish clams (Cowles 2007). Additionally, Gillespie et al. (1999) found a similar species of pea crab, *Pinnixa faba*, within many Varnish clams in British Columbia waters. The mussel pea crab has several life stages in which it may periodically be found outside its host, during which the shell hardens and its legs are densely fringed with setae for swimming (Wicksten 2009). Some of the pinnotheridae leg fragments found in my Padilla Bay fecal samples had dense setae, and the possibility of this crab being encountered more readily while outside the commensal host makes this an additional prey species to consider for scoter consumption.

Anderson et al. (2008) also reported that isopods and pinnotheridae crabs were the dominant crustaceans found in Surf Scoters taken from Padilla Bay in 2005 and 2006. In addition, Henny et al. (1991) found crab in 60% of Surf Scoter stomachs sampled in the fall and winter from Alsea Bay, an isolated estuary on the outer Oregon coast. Other sea ducks have displayed a preference for crabs as prey. Harlequin Ducks (*Histrionicus histrionicus*) in the Strait of Georgia preferentially consumed crabs at the highest frequency during their molting period (Rodway and Cooke 2002). Guillemette et al. (1992) found that Common Eiders were selecting for crabs at a higher frequency relative to their availability in the habitat, likely because crabs contained more organic energy content than the alternative prey, mussels and urchins. Padilla Bay was the one site in which bivalves were not the dominant prey item, instead crustaceans were found in 94% of Surf Scoter samples. The high organic energy content, combined with the softer shell of small crab species makes them an attractive prey item compared to many larger bivalve species.

Anderson et al. (2008) found in their survey of prior Surf and White-winged Scoter dietary studies that White-winged Scoters had higher mean consumption of gastropods and crustaceans. Surveys of Boundary Bay in 1974, and 1976 revealed that both Surf and White-winged Scoters ate more crustaceans during the summer than the winter period (Vermeer and Levings 1977). In a number of selected studies, barnacles were included as the dominant crustacean prey species (Vermeer and Levings 1977, Vermeer and Bourne 1982). In these studies, mussels were also present, and as barnacles are frequently found attached to mussels, their presence in scoter samples may have been incidental. However, in both studies, the barnacles were consumed during the summer, whole, and in large quantities which suggests they were consumed intentionally. Vermeer and Levings (1977) suggested that these were likely consumed to serve as grit, since there is little flesh value in barnacles. However, seasonal differences in prey availability may foster greater reliance on barnacles as a prey species throughout the year, in contrast to the greater diversity of prey items present during the molting period. Barnacles were found infrequently in my samples, generally amongst mussel fragments, and were not included in the final analysis.

Consumption of gastropods was greatest for Surf Scoters, despite prior evidence that White-winged Scoters consume a greater proportion of gastropods (Anderson et al. 2008). Almost all gastropods consumed were < 4.0 mm in size. Energy savings during the molting period can be achieved in a number of ways, one of which is to reduce the amount of shell material that is processed. Consumption of less shell material by eating smaller bivalves and gastropods relates to an increase in gizzard efficiency (DeLeeuw and Van Eerden 1992, Bustnes 1998, Guillemette 1998), compensating for increased metabolic demands during molt. DeLeeuw and Van Eerden (1982) found that Tufted Ducks (*Aythya fuligula*) selected for smaller mussels on deeper dives, which could be consumed below the surface rather than wasting time searching for larger mussels that had to be swallowed above water. Since many birds compensate either behaviorally or physiologically during the molt of flight feathers, scoters may be selecting for smaller, energy dense prey which can be more efficiently processed by the gizzard.

Foraging Behavior and Nutrition in Relation to Scoter Size:

Surf Scoters are smaller than White-winged Scoters, and have smaller, more flexible bills that may allow for greater feeding opportunities with prey that are smaller and more mobile (Goudie and Ankney 1986). The small size of many prey species consumed at the estuary sites with eelgrass habitat in this study highlights the diversity of feeding mechanisms being employed by Surf Scoters. Small estuarine invertebrates, such as the Eelgrass Isopod, as well as small crabs, and gastropods can be found attached to eelgrass blades. Observational evidence suggests that Surf Scoters may strip prey from the blades of eelgrass while underwater (Anderson, E., pers. comm.). Plant material was found in 17% of Surf Scoter samples from Boundary Bay, and 12% of Padilla Bay samples. These plants may be ingested incidentally while scoters fed on attached invertebrates, or as debris while feeding off the substrate surface (Stott and Olson 1973). The greater mobility of smaller sea ducks and the high energy content of small invertebrate prey may offset the need to consume larger prey items. Goudie and Ankney (1986) found that smaller sea ducks such as Harlequin Ducks and Oldsquaws (*Clangula hyemalis*) consumed a varied diet, with more energy dense small invertebrates, such as isopods and amphipods. In their study, despite the overlap in habitat, larger sea ducks such as Black Scoters (Melanitta nigra) and Common Eiders, were not taking advantage of the smaller prey items as much. Further studies of scoters during the molting period may aim at quantifying foraging behavior. However care should be taken in observations of above water feeding behavior, as evidence suggests that below surface feeding techniques may be more complex (De Leeuw and Van Eerden 1992).

Molting sea ducks that undergo a simultaneous wing molt would be expected to have high costs associated with the intensity of molting all flight feathers at one time. Birds that do not compensate behaviorally for these demands must meet their nutritional needs through available food resources. Scoters in the present study had body mass averages that were comparable to taxonomic averages, thus it does not appear that birds were lower in mass due to decreased foraging activities. Male and female White-winged

Scoters ranged from 1560 to 1180 g average mass, respectively, while Surf Scoters range from 1050 to 900 g, respectively (Brown and Fredrickson 1997, Savard et al. 1998). In this study, male and female White-winged Scoters averaged 1712 and 1502 g, respectively, while Surf Scoters averaged 1090 and 959 g, respectively. Dickson et al. (2010) found that molting White-winged and Surf Scoters from Puget Sound, WA, and the Strait of Georgia, BC, were not losing mass during the molting period in 2008 and 2009.

Comparative analysis reveals that female Surf Scoters at Padilla Bay are significantly lighter than the rest of their cohort at the other three molting locations (Evenson, J. unpubl. data). This has been true for each year of the banding study (2007-2009) indicating that the Padilla birds have consistently been the lightest in this cohort. Interestingly, a recent case study of Padilla Bay that synthesized prior seabird monitoring results over the last several decades revealed overall declines for marine birds, yet while most diving duck densities had declined, scoters had increased in the bay during the winter and spring seasons (Anderson et al. 2009a). The availability of diverse food resources at this site may be contributing to increased scoter presence, which in turn may contribute to greater competition for food resources, possibly resulting in birds of lower mass.

In general, since scoters do not appear to be losing mass on the molting grounds, they are likely meeting their nutritional needs through available food resources (Dickson et al. 2010). Hohman et al. (1992) reviewed studies of molting waterfowl diets during the breeding and post-breeding period, and found very little evidence to suggest that diet shifts tremendously during the molting period to meet protein requirements. Waterfowl were generally eating the same proportion of plant or animal matter in both periods. Waterfowl with less protein in their diets tend to lengthen the molting period, to provide for adequate protein synthesis for feather re-growth (Hohman et al. 1992, Thompson and Drobney 1997). Since scoters are relying on exogenous protein sources, the nutritional content of specific prey species consumed during the molting period may be highly informative.

Determination of the energetic content of invertebrate prey species is complicated by various factors such as time of year, burial depth, density, age, thickness of shell, as well as regional differences (Zwarts and Wanink 1993, Bustnes 1998, Larsen and Guillemette 2000, Richman and Lovvorn 2003). Many bivalve species may provide dramatically different energy estimates during bivalve spawning periods, as gonadal and egg development add energetic content (Thayer et al. 1973, Zwarts and Wanink 1993). Without quantitative sample analysis of prey species found at the molting sites, it is impossible to state absolute energetic differences. Yet comparative analysis from other studies tends to indicate that energetic density is generally greater for crustaceans and polychaetes, than bivalves and gastropods (Thayer et al. 1973, Goudie and Ankney 1986, Jorde and Owen 1988, Zwarts and Wanink 1993). The greater energy content is often related to the lack of hard shell material that must be processed by the gizzard. Guillemette et al. (1992) found energy content per gram live mass in mussels was about two times greater than that in sea urchins, while crabs had three times the energy content of mussels. Pinnotheridae crabs had some of the highest energy densities compared to bivalves, gastropods, polychaetes, and other crustaceans at an estuary site in North

Carolina (Thayer et al. 1973). This particular pea crab also has both soft and hard skeleton stages, in which energy densities would undoubtedly be highest in the soft stage.

It appears that Surf and White-winged Scoters may be partitioning their molting habitat to obtain preferred prey species, likely in accordance with scoter size. Both scoter species are capable of eating similar prey, yet Surf Scoters are selecting for non-bivalve prey species with high frequency in the eelgrass estuary habitats during the molting period. It would appear that there are strong energetic gains from this prey selectivity, which may range from the overall energetic content of non-bivalve prey, to the lighter shell processing required from a sea duck that is already physiologically compensating for feather re-growth. The dominance of mussels and Varnish clams at the remaining molting sites likely indicates that these bivalve species are readily available in these habitats. As such, it is important to maintain these molting habitats, as they provide the food resources necessary during this important life stage, as well as safety during the flightless period. Each of these sites has historically experienced varying levels of developmental pressure, from aquaculture operations, to pollution from upland sources. Just as scoter populations were likely affected by recently declining herring runs in the Puget Sound region, a single large incident or habitat modification at molting locations could drastically affect these sea ducks. For example, a major oil spill at the Padilla Bay estuary from local refineries could have devastating effects on the large numbers of waterfowl that utilize this habitat. Conversely, it is also possible that the appearance of an invasive species, such as the Varnish clam, could have positive ramifications for the needs of scoter species, as it is evident that both Surf and White-winged Scoters are consuming it in large quantities.

Have scoters selected traditional molting sites because food resources are abundant at these sites, or because specific food resources exist at these sites to provide for unique nutritional needs during this life stage? Based on the recent appearance of numerous molting scoters in the Fraser River delta concurrently with the initial expansion of Varnish clams, it would appear that specific food resources may be more influential. As waterfowl adjusted their migratory behavior to the appearance of Zebra mussels as a novel food resource in the Great Lakes, it would appear that scoters have done the same in the Pacific Northwest. I would argue that the specific prey species occurring with the greatest frequency in scoter samples from each of the molting locations are likely the reason that scoters return every year, just as herring spawn influence scoter movements during spring migration (Lewis et al. 2007b, Anderson et al. 2009b). Vermeer and Levings (1977) documented approximately 10,000 scoters, primarily Surf, congregating in Boundary Bay during the molting period in 1974. In Vermeer and Levings (1977) study, both scoter species ate more snails and crustaceans, and fewer bivalves in summer and fall, versus during the winter. The diversity of alternative prey consumed at the two estuary sites with eelgrass habitat in this study, Boundary Bay and Padilla Bay, mussels at Forbes Point, and Varnish clams at the Fraser River, are likely providing for the nutritional needs of molting scoters in a unique way. The absence of any adult Manila or Littleneck clams in any molting scoter fecal samples likely indicates their less desirable status as a prey species during this life stage.

If molting habitat selection is based on the preferential selection of certain prey species, then it is extremely important to protect and manage these habitats accordingly. Protection of eelgrass habitat in particular may require further emphasis, as many prior scoter studies have potentially over-emphasized the importance of bivalves as a dominant prey species, for Surf Scoters specifically (Anderson et al. 2008). Estuarine habitat is known to provide substantial resources for marine plants and animals, and the nutritional linkages in this habitat directly influence the productivity of various sea duck species (Stott and Olson 1973, Baldwin and Lovvorn 1994). Unfortunately, eelgrass habitat has undergone significant declines worldwide due to habitat change, pollution, invasive species, and decreased water clarity (Ralph et al. 2006). As annual stopover sites for migrating scoters, habitat conditions at these molting sites relate directly to the future fitness of scoter population. Additional quantitative analysis of prey species density, distribution, and biomass may lead to improved management for Surf and White-winged Scoters at these migratory stopover sites.

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Appendix A:

Nonmetric Multidimensional Scaling (NMS) Ordination Technique

Procedure is based on an *n* x *n* distance matrix, calculated from the *n* x *p* original species data matrix, in which *n* is the number of rows and *p* is the number of columns in the species data matrix. NMS describes the best combination of *n* entities (or sample units) on *k* dimensions in sample space, while minimizing stress. Stress is determined by the difference in the original *p* dimensional space and the distance described by the *k* dimensional ordination space. NMS allows for multiple distance measures, while rank-ordering of species space distances and ordination space distances linearizes their relationship. McCune and Grace (2002) provide the following variable definitions:

X = coordinates of n sample units or entities in a k-dimensional space. The element x_{il} is the coordinate of sample unit *i* on dimension (axis) *l*.

Δ = matrix of dissimilarity coefficients from the original data. Any distance measure can be used. We recommend using the quantitative version of the Sørensen coefficient for most ecological community data.

δ_{ij} = elements of Δ.

D = matrix of interpoint distances in the k-space. This matrix of *n* x *n* Euclidean distances is calculated from **X**.

d_{ij} = elements of **D**.

Raw stress:

$$S^* = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (d_{ij} - \underset{\wedge}{d}_{ij})^2$$

S^* measures the departure from monotonicity. If $S^* = 0$, the relationship is perfectly monotonic.

Stress is then standardized:

$$S = S^* / \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij}^2$$

Final stress is rescaled:

$$S_R = 100\sqrt{S}$$

(See McCune and Grace (2002) for additional detailed methodology).

Appendix B:

Multi-response Permutation Procedure Technique

To determine whether or not there is a difference between two or more test groupings, McCune and Grace (2002) outline the following procedure:

1. Calculate distance matrix **D**, utilizing distance measures such as Euclidean, or Sørensen distance measures.

2. Calculate the average distance x_i within each group i.

3. Calculate delta

$$\delta = \sum_{i=1}^{g} C_i x_i$$

for g groups, where C is a weight that depends on the number of items in the groups (normally $C_i = n_i / N$, where n_i is the number of items in group i and N is the total number of items). Note that all $n_i \geq 2$. For a given mean overall distance, smaller values of δ indicate tighter clustering within groups.

4. Determine probability of a δ this small or smaller. A reasonable method that is also applicable to medium or large data sets is to approximate the distribution of δ from a continuous distribution (Pearson type III). The Pearson type III distribution incorporates three parameters, the mean m, standard deviation s, and gamma g (skewness of δ under the null hypothesis).

The test statistic, T is

$$T = (\delta - m_\delta) / s_\delta$$

where m_δ and s_δ are the mean and standard deviation of δ under the null hypothesis. Or, in other words, the test statistic is the difference between the observed and expected deltas divided by the square root of the variance in delta.

$$T = (\text{observed } \delta - \text{expected } \delta) / \text{s.dev of expected } \delta$$

The test statistic, T, describes the separation between the groups. The more negative is T, the stronger the separation. The p-value associated with T is determined by numerical integration of the Pearson type III distribution.

5. A description of the effect size that is independent of the sample size is provided by the chance-corrected within-group agreement (A).

$$A = 1 - \delta / m_\delta = 1 - \text{observed } \delta / \text{expected } \delta$$

Appendix C:

Beals smoothing transformation procedure

This transformation provides a quantitative value that indicates the “favorability of a given sample for species *i*, based on the whole data set, using the proportions of joint occurrences between the species that do occur in the sample and species *i*”(McCune and Grace 2002).

$$b_{ij} = (1 / S_i) \sum_k (M_{jk} / N_k)$$

S_i = number of species in sample unit i

M_{jk} = number of sample units with both species j and k

N_k = number of sample units with species k

See McCune and Grace (2002) for an example of a data matrix before and after the Beals smoothing transformation.

Appendix D: Sum of total samples with prey items identified from Surf and White-winged Scoter fecal samples at four molting locations in Northern Puget Sound, and Southern Strait of Georgia, with total scoters in parenthesis (F = female, M = male).

	Boundary Bay		Forbes Point		Fraser River		Padilla Bay
	SUSC (9F, 3M)	WWSC (1F, 13M)	SUSC (7F, 8M)	WWSC (2F, 3M)	SUSC (8F, 10M)	WWSC (9F, 19M)	SUSC (48F, 3M)
Bivalvia	12	13	15	5	18	28	34
Mytilidae (Mytilus trossulus)	3	1	15	5	3	1	13
Cardiidae	11	2	0	2	0	0	2
Macoma balthica	0	0	0	0	2	0	0
Macoma sp.	1	0	0	0	0	0	1
Psammobiidae (Nuttallia obscurata)	1	8	3	1	18	28	18
Veneridae	7	2	0	0	3	1	3
Unidentified Bivalvia	2	1	0	0	0	0	7
Gastropoda	7	1	1	0	0	2	24
Pyramidellidae	0	0	0	0	0	0	8
Potamididae (Batillaria atramentaria)	0	1	0	0	0	0	1
Unidentified Gastropoda	7	0	1	0	0	2	18
Crustacea	5	1	1	0	1	2	48
Idoteidae	3	0	0	0	0	2	21
Cancridae	1	1	0	0	0	0	2
Pinnotheridae	0	0	0	0	0	0	34
Caprellidea (Caprella sp.)	0	0	0	0	0	0	2
Unidentified Crustacean	1	0	0	0	1	0	4
Amphipoda	2	0	1	0	0	0	0
Echinodermata (Ophiuroidea)	0	0	0	0	0	0	2
Polychaeta	6	0	0	0	0	1	6
Plant material	2	2	0	0	0	2	6

Appendix E: Wide-angle view above dissecting microscope of several Veneridae clams, with likely *Transennella* species on the right, and possible Manila clam on the left (several small gastropod species also pictured). Clams pictured < 3.0 mm in width, see calipers.