PREY SELECTION BY HARBOR SEALS IN RELATION TO FISH TAKEN BY THE GULF OF MAINE SINK GILLNET FISHERY

By

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As harbor seal (*Phoca vitulina concolor*) populations increase and commercial groundfish stocks dwindle in the Gulf of Maine, it is important to investigate the potential for competition between seals and fishermen. I aged 261 harbor seals from teeth or body measurements and identified prey from the stomach contents of 75 harbor seals caught in sink gillnets in the Gulf of Maine and adjacent waters from 1991 to 1997. Ninety three percent of seals caught in gillnets were less than four years old. Of 24 taxa identified, silver hake (*Merluccius bilinearis*) was found frequently (70.6% of stomachs), making up 52.1% of the prey items, and 40.8% of the reconstructed biomass. Silver hake, red and white hake, Atlantic cod, squid, and redfish (in IRI rank order) accounted for 77.7% of the reconstructed biomass and 87.4% of the number of prey consumed. Species richness was greatest in summer in northern Gulf of Maine diets (16 species) but more evenly distributed in winter in southern Gulf of Maine diets (13 species). Harbor seals utilized 11 of 22 commercial fish species landed by gillnet fishermen. Using the odds ratio with proportions of mass caught in sink gillnets and proportions of mass in the seal diets taken from the same nets, harbor seals selected silver hake, Atlantic herring, red or white hake, pollock, redfish, and Atlantic cod. Dogfish, monkfish, skates, American lobster, and flounder were among some species selected against by harbor seals. The mean length of prey was 22 cm. Harbor seals selected small, juvenile silver hake, red and white hake, Atlantic cod, pollock, and redfish compared to those taken in gillnets. The species and size composition of prey taken by harbor seals differed significantly from sink gillnet catches. Predation by these predominantly juvenile harbor seals had a minimum affect on fish populations targeted by the sink gillnet fishery and seals were not in direct competition with fishermen.

Key words: *Phoca vitulina concolor*, harbor seal, sink gillnet, stomach contents, food habits, prey importance, prey preference, fishery interactions, Gulf of Maine.

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INTRODUCTION

Western Atlantic harbor seals (*Phoca vitulina concolor*) are often blamed for reducing fishery yields by allegedly feeding on valuable fish resources, destroying gear, damaging fish in nets, transmitting parasites to fish, scaring fish from traditional fishing grounds, and stealing bait (Allen 1942, Brown 1983, Gilbert and Wynne 1983, Kellert *et al.* 1995, Lavigne 1991, Stobo and Fowler 1994, Woodley and Lavigne 1991, Woodley and Lavigne 1995). Seals have a reputation for reducing the quality and quantity of commercially important fish and invertebrates, although supporting evidence is often lacking. Very little is known about the diets of harbor seals in the Gulf of Maine. Previous dietary studies have been limited to Atlantic Canada (Boulva and McLaren 1979, Bowen and Harrison 1996), Maine (Hunt 1946), and southern Massachusetts (Payne and Selzer 1989). Seals hold a dynamic role in regulating the abundance of species, transferring nutrients and energy, and influencing the physical complexities of their environment (Trites 1997). Commercial fisheries may actually benefit by seals consuming predators and competitors of some of the more desirable species (Wallace and Lavigne 1992). Obtaining data on the diet of seals and assessing food selection relative to abundance are important steps in investigating the role of seals in the marine ecosystems (Boyle 1997) and is essential in assessing the effects of seals preying on commercial fish and predicting seal entanglements.

Aerial surveys in 1997 estimated a minimum of 30,990 harbor seals in Maine and New Hampshire, where they are year-round residents and compose the majority of breeding and pupping; a 7.6 percent increase since 1993 (Gilbert and Guldager 1998). The historical range of harbor seals, from Arctic Canada to New York, had not changed substantially over the past century (Payne and Selzer 1989) but, surveys are currently underway to examine the seasonal flux of the harbor seal range in and out of southern New England states. Harbor seals were once hunted in the northeastern United States and Canada for their supposed role in affecting stocks of fish which resulted in total extermination of seals in some areas (Boulva and McLaren 1979, Payne and Selzer 1989). In 1972 intentional killing was prohibited under provisions of the U.S. Marine Mammal Protection Act (MMPA). The MMPA outlaws all marine mammal takes, i.e. attempts or actual acts of harassing, hunting, capturing, or killing marine mammals by human activities in the United States (Marine Mammal Commission 1995). However, limited exemptions are allowed for takes of low numbers of marine mammals incidental to certain activities, including commercial fishing. Seal populations in the Gulf of Maine (GOM) have recovered because of protection instituted in the 1970's. Kenney and Gilbert (1994) reported an increase in numbers and amount of pupping of harbor seals, along with expanded use of habitat in Maine. Although, the average annual increase in 1997 was not as great as in previous years indicating that the population may not be increasing as rapidly, the number of pups has increased at an annual rate of 12.9 percent since 1981 (Gilbert and Guldager 1998). The recent increase of seals has the potential to increase conflicts between commercial fisheries and seals.

Overfishing has left severely depleted groundfish populations in New England, in particular Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and yellowtail flounder (*Limanda ferruginea*), which has forced emergency closures and restrictions on fishing effort and gear configurations (Anthony 1993, Federal Register 1998). Fishing mortality of Gulf of Maine cod remains well above the management target selected to allow the stock to recover and must be substantially reduced to prevent further declines in spawning stock biomass (Clark 1998). Gulf of Maine silver hake (*Merluccius bilinearis*) is considered over-exploited due to rapid removal of recruits in recent years (Clark 1998). Redfish (*Sebastes* spp.) and pollock (*Pollachius virens*) are considered fully exploited and catches must remain low to allow recovery to continue (Clark 1998).

In 1992, the sink gillnet fishery was the second largest groundfish harvesting industry in the northeastern United States, with annual landings of 17,000 metric tons worth $16 million (Lazar 1993). In 1996, Northeast gillnet vessels landed over 30,000 metric tons of fish with a revenue of $29 million (Clark 1998). Gillnet vessels target several of 10 groundfish species, managed by the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan under the Magnusun-Stevens Fishery Conservation and Management Act (NOAA 1996). Sea birds, sea turtles, and marine mammals occasionally become entangled in gillnets which may result in serious injury or death (Read *et al.* 1994, Waring *et al.* 1997). Because sink gillnet vessels take significant numbers of marine mammals, including white-sided dolphins (*Lagenorhynchus acutus*) and harbor porpoise (*Phocoena phocoena*), they are required to carry observers certified by the National Marine Fisheries Service, if requested. Beginning in 1989, observers were deployed on domestic commercial fishing vessels to collect information on fishing activity, catch composition, and incidental takes of marine mammals. The average number of harbor seal mortalities attributable to the sink gillnet fishery during 1992-1996 was estimated at 898 seals annually, increasing from 373 harbor seals in 1992 to 911 seals in 1996 (Waring *et al.* 1999). The combined increase in seal abundance and reduced fish stocks will undoubtedly escalate conflicts between humans and seals.

I will investigate the seasonal and temporal variation in the diet of harbor seals by examining the stomach contents of seals killed in Gulf of Maine sink gillnets in relation to fish catch. My objectives are to 1) describe harbor seal food habits near commercial fishing grounds and 2) describe harbor seal interactions with the sink gillnet fishery. In particular, I will 1) describe observer coverage of the Gulf of Maine sink gillnet fishery, 2) describe the age, spatial, and temporal distribution of harbor seal by-catch, 3) examine the species and size of prey eaten by harbor seals taken in gillnets, 4) compare fish taken by seals relative to sink gillnet catch, and 5) describe the fish catch damaged resulting from seal predation.

METHODS

Observer coverage of the Gulf of Maine sink gillnet fishery

From 1991 to 1997 observers were deployed on commercial sink gillnet vessels as required by the MMPA. The information collected included fishing activity, gear characteristics, catch composition, and incidental takes of marine mammals. Observers also collected biological samples and length frequencies of fish taken and fish discarded.

Most sink gillnetting occurs in 55 to 85 m inshore waters, with some fishing offshore in 115 to 185 m of water. Monofilament gillnets have a mesh size from 14 to 30.5 cm and twine size of 8 to 14 gauge (0.47-0.62 mm diameter). Gillnet strings range from 550 to 1830 m long, comprised of several 91-m-nets linked together. The string with nets attached is set on the bottom, weighted down by a lead-filled line and anchors. A buoyant head rope, made of foam-core rope or twisted polypropylene with floats keeps the net vertical. Tie downs, 0.8 to 1 m high, are sometimes used to adjust the fishing height of the nets by cinching the floatline closer to the leadline. The nets are left fishing in the water from one to four days. The gear fishes selectively by altering the head rope material, tie down height (fishing net height), mesh size, and soak duration (Hamley 1975, Lazar 1993, Marais 1985).

Geographical, seasonal, and age distribution of harbor seals taken

I categorized the seals taken in the gillnet fishery into two spatial areas and two seasonal areas. The samples collected north of Cape Ann, Massachusetts (42° 45' N), including the coastal waters of New Hampshire and Maine were classified as region "north". Region "south" samples were collected in Massachusetts Bay and south to Block Island Sound, New York. The "summer" season was designated as April through September and "winter" as October through March. I plotted locations of observed gillnet hauls and harbor seal by-catch and processed harbor seal teeth and stomach samples.

The lower mandible was removed from by-caught seals and tagged, either at sea or in the lab if the animal was brought in whole. The samples were frozen within several hours of collection. An age, to the nearest 0.1 year, was estimated for each seal, assuming a mean birth date of June 1st. Boulva and McLaren (1979) used a mean birthday of May 25th for seals on Sable Island in eastern Canada. Harbor seal pupping in the GOM has been reported between the end of May and the beginning of June (Boulva and McLaren 1979, Gilbert and Stein 1981, Temte *et al.* 1991).

I cleaned the jaws by maceration in a 1 cm-mesh eel pot set in ocean water. I double-wrapped the jaws in a mesh bag to prevent the loss of small teeth. I removed the canines and incisors immediately after soaking. The jaws were air-dried for several days and archived in plastic resin boxes. The teeth were temporarily stored in buffered formalin to prevent over-drying and cracking.

I followed methods of Stewart *et al.* (1996) for decalcifying, thin sectioning, and staining the teeth. I determined age from counts of cementum annuli in canines using a compound microscope at 40-200 X magnification. When the cementum is viewed in a stained section, a translucent band and dark band together make up an annual growth layer group (Dietz *et al.* 1991, Mansfield and Fisher 1960, McCann 1993). Each slide was examined independently by two readers. If there was disagreement, the slide was re-examined until a consensus was reached.

Growth curves may be produced from lengths of known-age seals and used to predict the age of other individuals (McLaren 1993). Not all by-caught seals were completely sampled so I used total length to estimate age for seals with length measurements and no teeth samples. For seals with annuli counts, I plotted the age-length relationship and compared it to those of seals of known length and age from New England Aquarium Stranding Program records (Payne and Selzer 1983). After examining the age-length regressions to confirm similarity, I classified the harbor seals into three broad age-classes that fit my study ("pup" < 107 cm or < 1 year; "juvenile" 108-130 cm or 1-3 years; and "adult" > 130 cm or > 3 years old).

Foods of harbor seals taken in gillnets

Observers ligated the seal stomachs at the esophageal and pyloric sphincter, double bagged, and froze the sample usually within 8 hours of retrieval. In the lab, I thawed the stomachs and noted the condition to ensure that contents had not been lost through holes in the stomach lining. I weighed the full stomach to the nearest 0.1 g. I opened the stomachs in a dissecting tray, before the contents were fully defrosted so that whole pieces of fish could be examined, weighed, and measured. Seals ingest most of their prey whole (Loughlin 1982, Woodley and Lavigne 1995). However, in case seals may not be ingesting whole fish, I recorded any evidence of bites or chunks of undigested food. To address the problems of content contamination by secondary-consumption (Blackwell and Sinclair 1995), I also evaluated the contents of stomachs of ingested fish.

The contents were passed through a series of nested brass U.S. standard testing sieves with mesh diameters of 0.425 mm, 1.0 mm, and 4.75 mm (Murie 1987). Teleost sagittal otoliths, skulls, dentaries, operculums, and articulated vertebral columns were removed, gently washed, and stored dried for identification and measurements (Crockford 1998, Fitch and Brownell 1968, Hansel *et al.* 1988, Hyslop 1980, Pierce *et al.* 1991, Treacy and Crawford 1981). Eye lenses of fish and squid were counted. Cephalopod beaks were identified to species, measured, and stored in 70% ethanol (Clarke 1986). Nematodes were separated and weighed. The empty stomach lining was weighed and subtracted from the full stomach weight to determine the weight of the wet contents.

I ranked the state of erosion of the otoliths from 1 (fresh out of the skull with fine definition of the sulcus and ridges) to 3 (severe where the length and shape was eroded to a smooth surface, chipped or broken). I recorded the number of otoliths recovered from skull cases in the stomach contents (Murie and Lavigne 1986). Right and left otoliths and upper and lower beaks were paired when possible, and the component with the greater number was used to determine the number of prey eaten. I measured the length, width, and depth of otoliths and the upper hood length and lower rostral length of beaks with vernier calipers to the nearest 0.1 mm (Croxall 1993). I identified species by comparing parts and whole specimens to a laboratory reference collection at the Northeast Fisheries Science Center, referencing guides (Brodeur 1979, Clarke 1986, Ford 1937, Härkönen 1986, Morrow 1979, Mujib 1967, Williams and McEldowney 1990), and from my own experience with otolith extraction.

I estimated the size and weight of prey at ingestion from measurements of undigested hard parts, using published regression equations listed in Table 1. As otoliths are composed of calcium carbonate and vary in surface area and shape by species, they will erode from gastric activity at different rates and can yield regression estimates that are negatively biased (Jobling and Breiby 1986, MacDonald *et al.* 1982, Prime 1979, Sekiguchi and Best 1997). Otoliths and beaks that were severely eroded were not measured or used for regressions. To estimate the length and mass of species not listed in Table 1, length and weight measurements were averaged from observer length frequency data. To verify the accuracy of the equations, I visually compared all otoliths to otoliths of known-length fish.

Table 1. Regression equations used to estimate lengths of harbor seal prey. All lengths are in millimeters and weights are in grams.

Prey Species	Regression Equations [a]	Sources
Atlantic cod	$ln\mathrm{FL}/10 = 3.3138 + 1.6235ln(\mathrm{OL}/10)$ $\mathrm{W} = 0.0084(\mathrm{FL}/10)^{3.021}$	Hunt 1992 Benoit & Bowen 1990
Atlantic herring	$\mathrm{FL} = 69.23(\mathrm{OL}) - 27.48$ $log_{10}\mathrm{W} = 3.12log_{10}(\mathrm{FL}) - 5.41$	Recchia & Read 1989 Recchia & Read 1989
Butterfish	$\mathrm{TL} = -9.15919 + 25.01871(\mathrm{OL})$ $log_{10}\mathrm{W} = -0.67576 + 3.222(log_{10}\mathrm{OL})$	Gannon *et al.* 1998 Gannon *et al.* 1998
Long-fin squid	$log_{10}\mathrm{ML} = 1.767 + 1.4log_{10}(\mathrm{LRL})$ $\mathrm{W} = 0.25662(\mathrm{FL}/10)^{2.1582}$	Gannon *et al.* 1997*a* Lange & Johnson 1981
Ocean pout	$\mathrm{FL}/10 = 11.045 + 6.23(\mathrm{OL})$ $\mathrm{W} = 0.001735(\mathrm{FL}/10)^{3.29}$	Bowen & Harrison 1996 Kohler *et al.* 1970
Pollock	$ln\mathrm{FL}/10 = 3.251 + 1.6251ln(\mathrm{OL}/10)$ $\mathrm{W} = 0.0134(\mathrm{FL}/10)^{2.94}$	Härkönen 1986 Bowen & Harrison 1996
Red/white hake	$\mathrm{FL}/10 = 1.525(\mathrm{OL}^{1.1456})$ $\mathrm{W} = 0.003998(\mathrm{FL}/10)^{3.1718}$	Clay & Clay 1991 Clay & Clay 1991
Redfish	$\mathrm{FL} = 16.165(\mathrm{OL}^{1.224})$ $\mathrm{W} = 0.0741(\mathrm{OL}^{3.295})$	Härkönen 1986 Härkönen 1986
Sand lance	$\mathrm{FL}/10 = -4.377 + 9.024(\mathrm{OL})$ $\mathrm{W} = 0.371(\mathrm{OL})^{3.89}$	Bowen *et al.* 1993 Bowen *et al.* 1993
Short-fin squid	$\mathrm{ML}/10 = 300.70log_{10}(\mathrm{UHL}) - 123.92$ $\mathrm{W} = 0.0187(\mathrm{ML}/10)^{3.03}$	Lilly & Osborne 1984 Clay & Clay 1991
Silver hake	$\mathrm{FL} = 20.9(\mathrm{OL}) - 0.41$ $\mathrm{W} = 0.0059(\mathrm{FL}/10)^{3.05}$	Recchia & Read 1989 Bowen & Harrison 1996
Winter flounder	$\mathrm{FL}/10 = 8.559 + 8.389(\mathrm{OL})$ $\mathrm{W} = 0.0079(\mathrm{FL}/10)^{3.12}$	Bowen & Harrison 1996 Bowen & Harrison 1996
Yellowtail flounder	$\mathrm{FL}/10 = 6.979 + 6.709(\mathrm{OL})$	Bowen *et al.* 1993

[a] Regression Equations: FL = fish fork length, TL = fish total length, ML = squid mantle length, W = wet weight, OL = fish otolith length, LRL = squid beak lower rostral length, UHL = squid beak upper hood length.

The relative importance of prey species was described by frequency of occurrence, proportions of numerical abundance, proportions of reconstructed mass, and Index of Relative Importance (IRI). Frequency of occurrence is the number of seals feeding on a particular prey species. Percentage frequency of occurrence of a prey species (%*F*) is the number of samples containing remains of one or more individuals of that prey type, expressed as a percentage of the number of non-empty samples (Hyslop 1980, Bigg and Perez 1985, Pierce and Boyle 1991). It is the proportion of seals feeding on that food type, regardless of the amount (mass and number) of the prey. Percent of numerical abundance (%*N*) is the minimum number of individuals of a prey species present in the stomachs, expressed as a percent of the total number of individuals from all stomachs. Since otoliths were paired, counts provided a minimum number of prey present in each sample. The counts are totaled by prey type and divided by the total number of individuals of all species eaten. This approach doesn't consider mass or volume of the prey consumed. Percent mass (%*M*) is the reconstructed weight of each prey species when it was eaten, expressed as a percent of the total reconstructed mass found in all stomachs. This quantifies the biomass of each prey species, indirectly accounting for number and size of prey items. IRI is a commonly used method that combines all three diet measures and may allow a more representative feeding-habit summary (Cailliet *et al.* 1986, Hyslop 1980, Pinkas *et al.* 1971, Young and Cockcroft 1994). The percent frequency of each prey species is multiplied by the sum of the percent mass and percent abundance to yield an index for comparison among prey species. For 11 of the most common prey species, the IRI was calculated:

$$\text{IRI} = (\%N + \%M)(\%F). \quad (1)$$

I separated the sample, into four groups (north/winter, north/summer, south/winter, south/summer) to test for spatial and seasonal differences in seal diet. I used percent frequency of occurrence to examine the diversity of the seal diets across the groups.

Comparison of fish taken by harbor seals and sink gillnets

Sampling protocols and data collection varied based on the type of observer coverage. For all hauls, observers recorded the target (sought after) species and weights of the kept portions of the catch. A subset of those hauls were observed and included the mass of discarded catch (fish that were caught but not kept for various regulatory or quality reasons). Observers also collected length frequencies on a sub-sample of the catch. When a seal was taken in the net, samples and measurements of the mammal took priority over recording fish discards and length frequencies.

I compared seal diets to gillnet catch in five ways. First, I compared the reconstructed mass of the seal diets to the mass of fish that were kept from the exact string of nets that had caught seals to see if the seals had fed on the same species that the fishermen were landing. Second, I compared the reconstructed mass of the seal prey to the kept and discarded catch from the exact net in which the seal was caught (only stomach samples that included both kept and discarded catch information were included). Third, I compared the length of fish from the seal stomachs to the standard lengths of fish discards and kept fish in the GOM gillnet fishery. Fourth, I examined the difference in stomach fullness and prey species composition within the different sub-fisheries, based on the targeted catch. Fifth, I looked at the species, amount, and frequency of fish that were partially eaten in gillnets, allegedly by seals, and therefore discarded.

I compared the rankings of fish species by percent mass in the seal diets with the rankings of the landed catch in the gillnets using a Mann-Whitney U-test (Zar 1984). I used the odds ratio to examine the extent of selection of prey by harbor seals on the gillnet catch (Fleiss 1981):

$$ln(O) = ln[(p_1 q_2)/(p_2 q_1)], \quad (2)$$

where p_1 = proportion of harbor seal diet consisting of a given prey item;

q_1 = proportion of harbor seal diet contributed by all other prey items;

p_2 = relative proportion of abundance of a given prey item in the net; and

q_2 = relative proportion of abundance of all other prey items in the net.

Values were calculated on percent reconstructed mass among seals and percent biomass caught in each sink gillnet that caught a harbor seal and stomach contents were analyzed. By taking the natural log of the odds ratio, positive values indicate prey which were positively selected and negative values indicate potential prey which were negatively selected.

I compared frequency distributions of fish lengths in stomach and net samples for silver hake, red/white hake *(Urophycis* spp.), Atlantic cod, pollock, and redfish. I used 5-cm size classes for all data sets. The length-frequency distributions for five prey species were plotted for fish eaten by seals, fish caught in the net and kept, and fish that were caught and discarded. Data sets were compared using Kolmogorov-Smirnov goodness of fit test (Zar 1984).

I separated the stomach samples by the target species of the gillnet in which the seal was caught (primary fish species sought) to test for differences in harbor seal prey and stomach fullness in four sink gillnet sub-fisheries: 1) target species of mixed groundfish including Atlantic cod, haddock, pollock, and white hake (*Urophycis tenuis*), 2) target species of mixed flounders including yellowtail flounder, winter flounder (*Pseudopleuronectes americanus*), and American plaice (*Lophopsetta maculata*), 3) target species of spiny dogfish (*Squalus acanthias*), and 4) target species of monkfish (*Lophius americanus*). Relative stomach fullness index (SFI) (Bernard and Hohn 1989, Robertson and Chivers 1997) of seals was averaged for each sub-fishery. The relative SFI is given as a percentage, by dividing the index for each stomach by the maximum index value in my sample:

$$SFI_{rel} = [(w_c/w_i) / SFI_{max}] \times 100, \quad (3)$$

where w_c = weight of the stomach contents (g); and

w_i = weight of the stomach with contents (g); and

SFI_{max} = maximum stomach fullness index in my sample; and

SFI_{rel} = percent relative stomach fullness index.

Observers recorded the weights of the fish discards along with the reason for discarding the catch. Discard reasons were grouped as 1) market or regulation restrictions, 2) hagfish (*Myxine glutinosa*) damage, 3) sand flea damage, 4) seal damage, and 5) overall poor quality. For observed gillnet hauls, I totaled the mass and occurrence of fish, by species, that were allegedly partially eaten by seals. I compared the average mass discarded per haul for each discard reason for fish species that were likely to be eaten by seals. To see if the discards due to seal-damage were a significant loss, I summarized the mass discarded by each of the discard reasons for the key fish species.

RESULTS

Observer coverage of the Gulf of Maine sink gillnet fishery

Observer coverage of the sink gillnet fishery extended approximately from the Jonesport, Maine to Block Island Sound, New York in the summer (Figure 1) and from Casco Bay, Maine to Block Island Sound, New York in the winter (Figure 2). Following fishing trends, coverage was reduced in offshore waters and in Maine during the winter months. Observations were made of 295 harbor seals killed in GOM sink gillnets. From those incidental takes, 119 jaw samples and 75 stomachs were collected. Most harbor seal takes occurred along or within the 50 fathom contour (Figure 3, Figure 4). Harbor seal takes were more dispersed in inshore waters during the summer (Figure 3), becoming more aggregated and further offshore during the winter (Figure 4). In the winter, most of the seal takes occurred south of Maine and were concentrated in Massachusetts Bay and Jeffreys Ledge. Stomach samples were well dispersed among the take locations, although were limited in the region south of Cape Cod. Fishing effort occurred in all months and harbor seals were taken in all months. Harbor seal incidental takes peaked in March and April, declined during pupping season in May, increased in July, declined after molt in August, and increased again during dispersal beginning in October (Table 2).

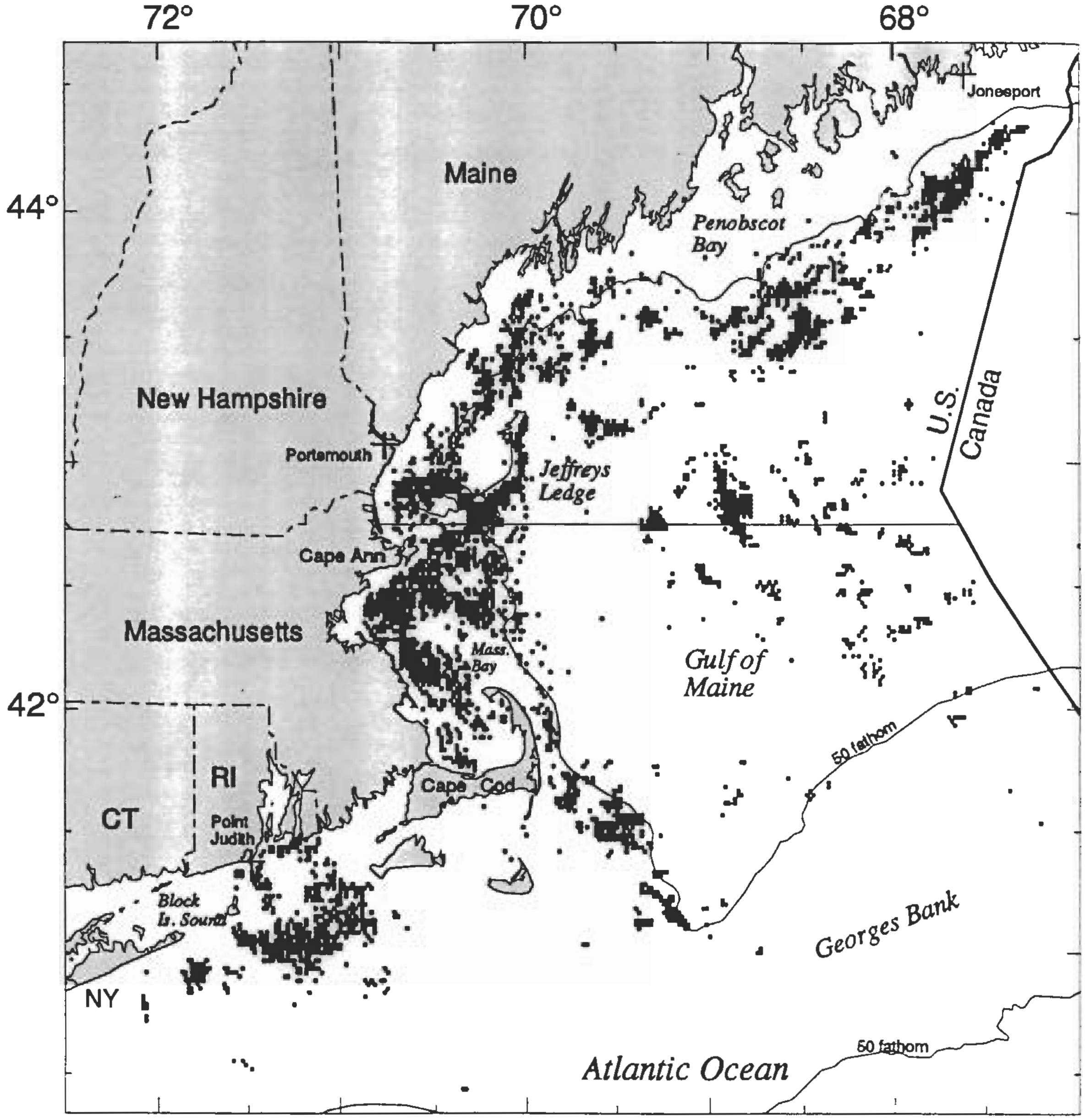

Figure 1. Summer (April through September) location of sink gillnet hauls covered by the Northeast Fisheries Observer Program, 1991-1997. Northern and southern areas are separated by the line drawn at 42° 45' N.

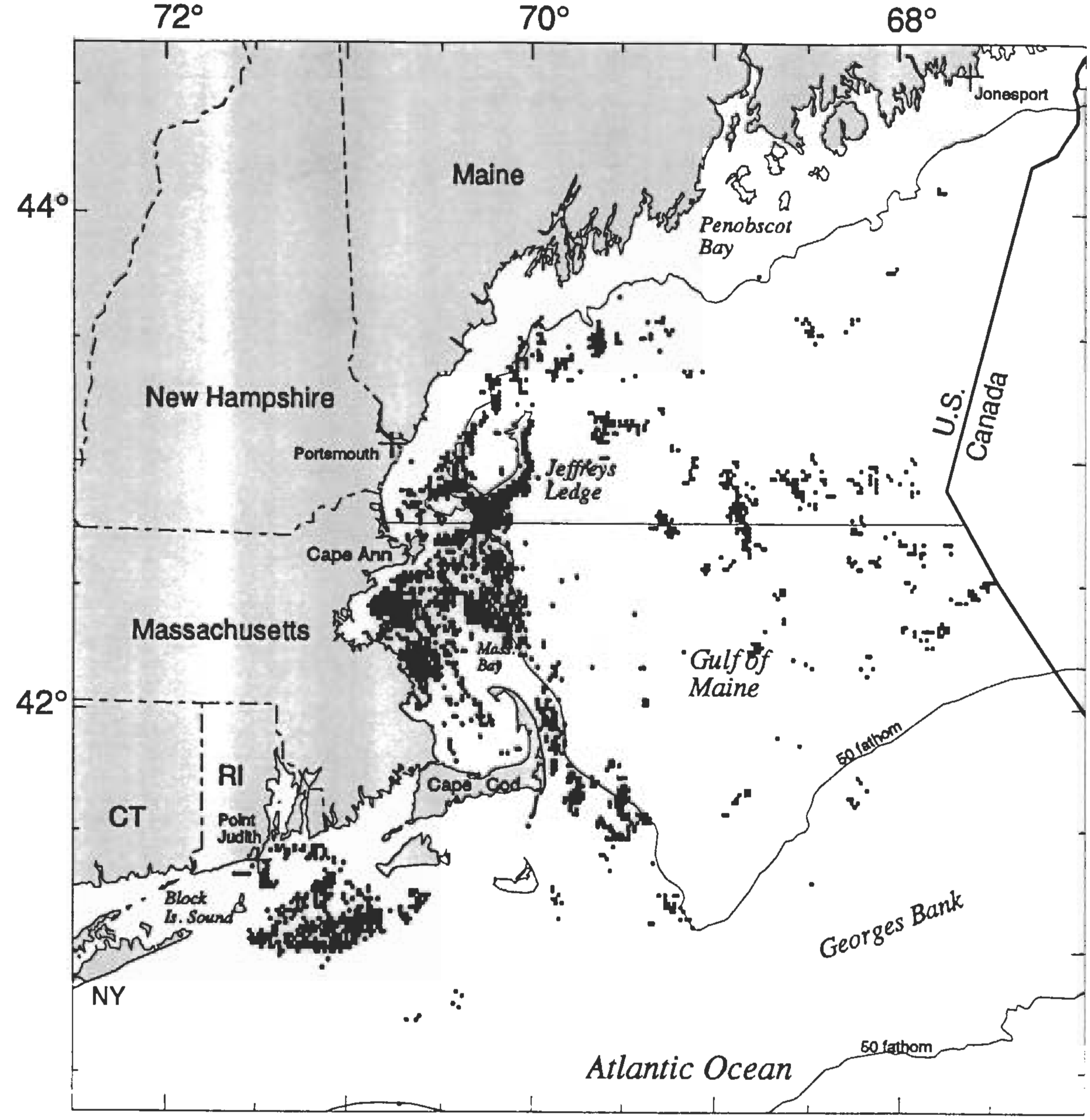

Figure 2. Winter (October through March) location of sink gillnet hauls covered by the Northeast Fisheries Observer Program, 1991-1997. Northern and southern areas are separated by the line drawn at 42° 45' N.

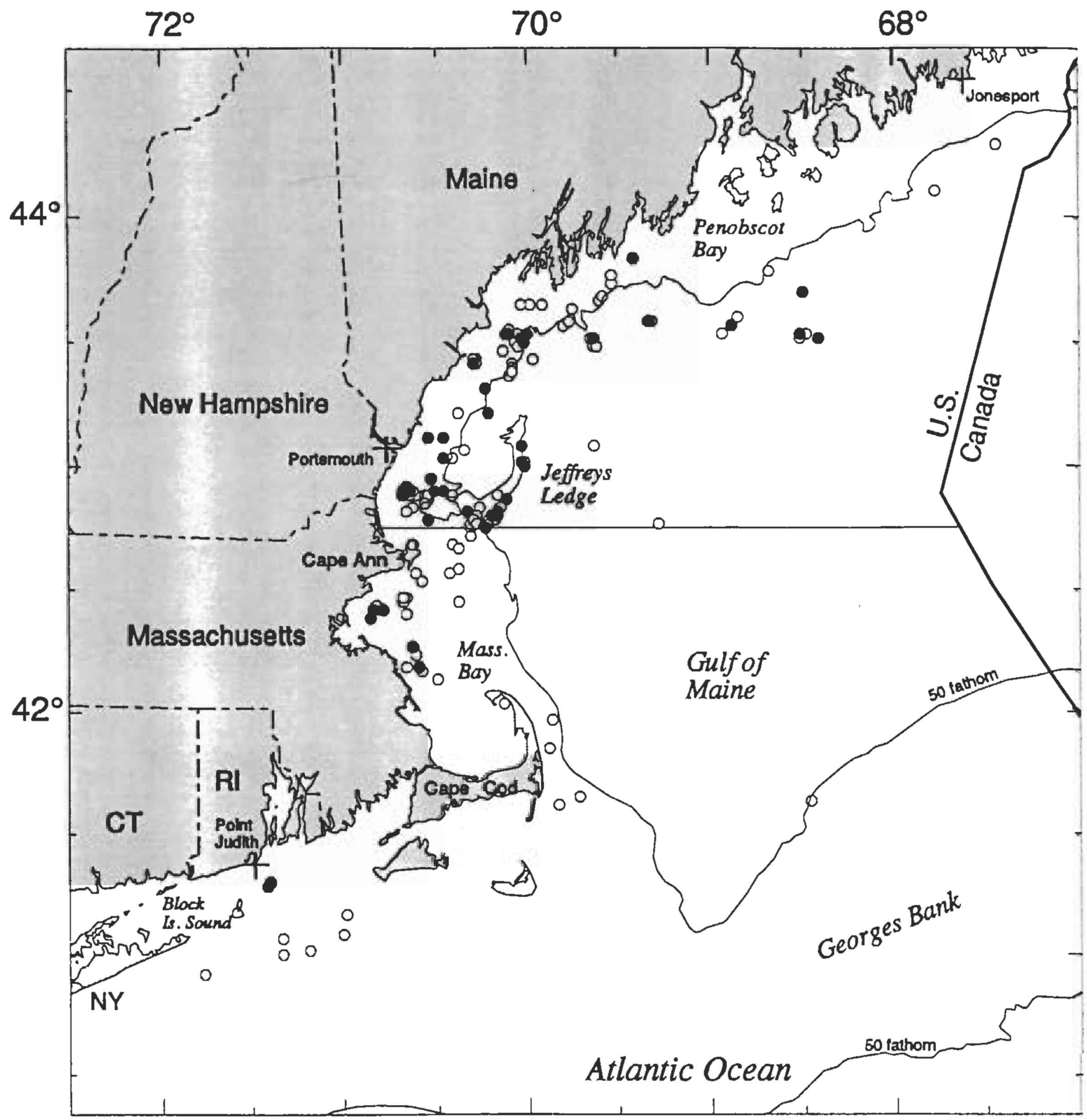

Figure 3. Summer (April through September) location of harbor seal incidental takes in sink gillnet hauls reported by the Northeast Fisheries Observer Program, 1991-1997. Open circles represent seal takes with no sampling, filled circles represent locations of stomach samples. Northern and southern areas are separated by the line drawn at 42° 45' N.

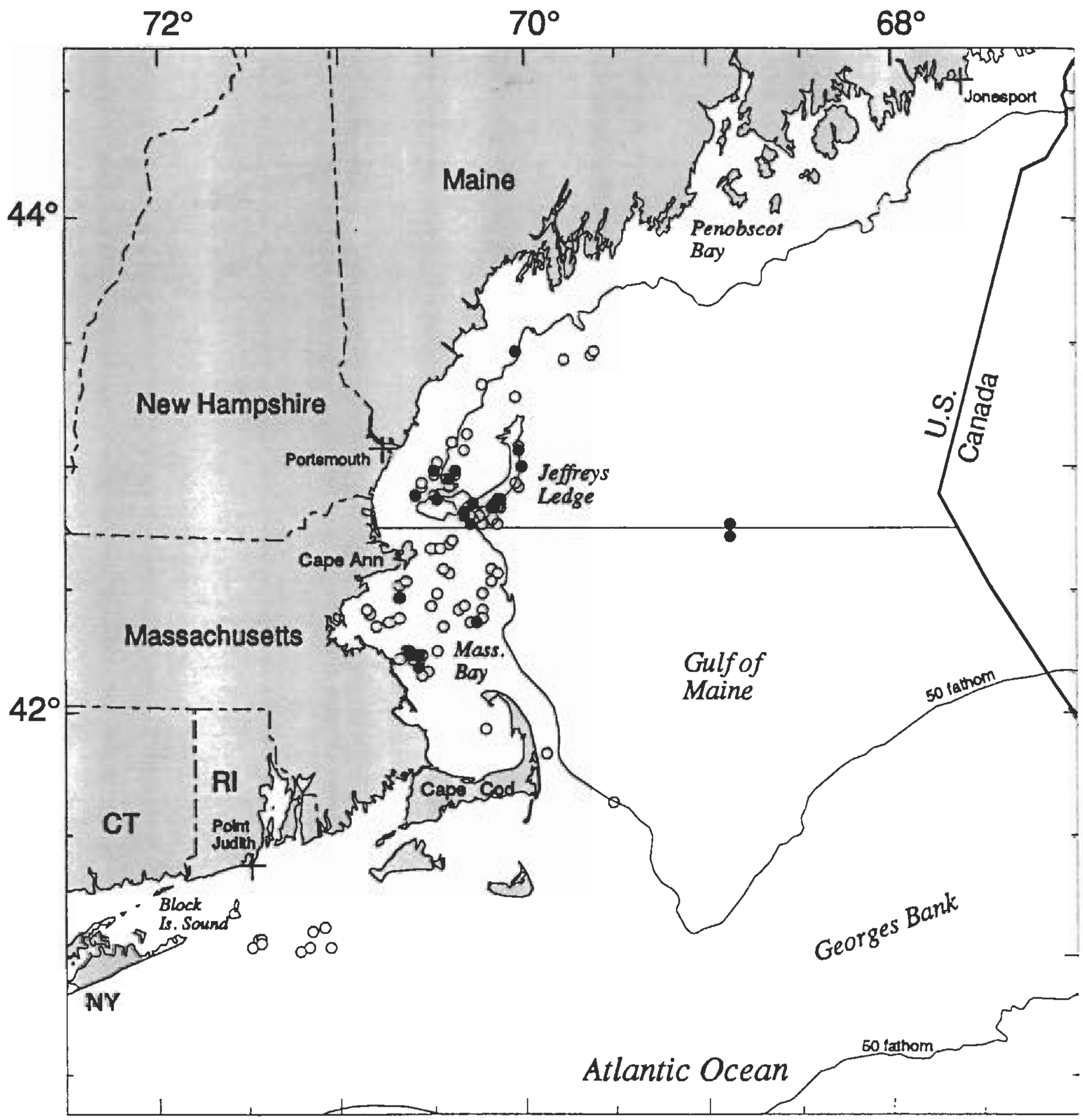

Figure 4. Winter (October through March) location of harbor seal incidental takes in sink gillnet hauls reported by the Northeast Fisheries Observer Program, 1991-1997. Open circles represent seal takes with no sampling, filled circles represent locations of stomach samples. Northern and southern areas are separated by the line drawn at 42° 45' N.

Table 2. Total number of sink gillnet hauls and harbor seal incidental takes observed and sampled each month in the Gulf of Maine, 1991-1997. The number of hauls can be used as a measure of observer effort. The ratio of seals to hauls is the probability of catching a harbor seal, showing the highest take-rates in March and July.

Month	Number of Sink Gillnet Hauls	Number of Harbor Seal Takes	Number of Stomach Samples	Ratio of Seals To Hauls
January	813	5	2	0.0062
February	792	11	2	0.0139
March	1364	31	0	0.0227
April	3126	38	6	0.0122
May	4313	14	5	0.0032
June	3148	10	0	0.0032
July	3205	61	8 (1)[a]	0.0190
August	3171	23	19 (4)[a]	0.0073
September	2556	10	5 (1)[a]	0.0039
October	3013	33	8 (1)[a]	0.0110
November	3514	30	10	0.0085
December	1920	29	10	0.0151

[a] Number of stomachs containing an insignificant amount of food is in parentheses.

Geographical, seasonal, and age distribution of harbor seals taken

Of the observed takes of harbor seals that were age-classified from teeth samples (n=69) and length measurements (n=192), 71% were pups, 22% were juveniles, and 7% were adults. Those seals takes with a stomach sample (n=75), of which 52 ages were based on annuli and 23 ages were based on length, were similarly represented by 70% pups, 28% juveniles, and 2% adults. The oldest seal aged in my sample (n=261) was 8 years old. Since my sample of by-caught seals lacked adult samples, I could not test for statistical differences between growth curves of by-caught and known-age seals. However, by visual comparison of the plots, the growth rates seemed consistent. None of the stomach samples had the presence of milk, indicating that all taken pups were weaned. The number of harbor seal takes was the highest for pups and least for adults in the northern region during the summer months (Table 3). Table 3 summarizes the number of samples for each category based on geographical region, season, and age class of the seal. The seals were not classified by sex, as a significant fraction were undetermined and some may be unreliable.

Table 3. Number of harbor seals and stomachs collected in Gulf of Maine sink gillnets, categorized by region, season, and age-class. The northern region includes Maine south to Cape Ann, Massachusetts and the southern region extends from Cape Ann to Block Island Sound, New York. The seasons are summer (April through September) and winter (October through March).

Region	North						South					
Season	Summer			Winter			Summer			Winter		
Age-class [a]	P	J	A	P	J	A	P	J	A	P	J	A
Number of Harbor Seals Taken	83	8	1	36	14	4	34	11	7	36	27	6
Number of Stomachs Collected	29 (4)[b]	6	1	15	7 (1)[b]	1	5 (2)[b]	2	0	3	6	0

[a] Age-class: P = pups < 1 year old, J = juveniles 1-3 years old, A = adults ≥ 4 years old.

[b] Number of stomachs containing an insignificant amount of food is in parentheses.

Foods of harbor seals taken in gillnets

The 75 (68 non-empty) harbor seal stomachs contained 981 prey items, comprised of 22 fish species and two species of cephalopods (Table 4). Seals fed primarily on squid and fish from the Orders Gadiformes, Perciformes, and Clupeiformes. No evidence of lobster (*Homarus americanus*) was found in the seal stomachs. Parasitic nematodes, family Anisakidae, were present in all stomachs. The number of prey taxa per stomach ranged from zero to nine, with most (30%) of the stomachs containing two prey taxa. Seventy-five percent of the stomachs had one to three prey taxa. Nine percent of my samples had insignificant or no food remains in the stomach and were considered empty.

Table 4. Number and mean size of prey items found in 75 harbor seal stomachs, 68 of which contained food, sampled in Gulf of Maine sink gillnets, 1991-1997.

Prey Item	Number of Items	Length Range (mm)	Mean Length ± S.D. (mm)	Mean Mass ± S.D. (g)
Silver hake	511	50 - 500	219 ± 64	92 ± 81
Redfish	113	60 - 261	162 ± 42	42 ± 26
Red and white hake	101	42 - 380	194 ± 67	68 ± 65
Atlantic cod	63	60 - 610	253 ± 106	233 ± 358
Squid, mixed	46	198	198	174
Pollock	41	60 - 310	207 ± 66	126 ± 93
Atlantic herring	36	153 - 350	253 ± 46	134 ± 69
Short-fin squid	18	110 - 238	196 ± 32	143 ± 70
Ocean pout	14	173 - 400	249 ± 63	84 ± 82
Long-fin squid	6	123 - 338	232 ± 84	259 ± 180
Alewife	5	280 - 350	298 ± 30	250
Butterfish	5	66 - 91	77 ± 12	4 ± 2
Winter flounder	4	262 - 346	315 ± 46	390 ± 158
Atlantic wolffish	3	230 - 400	343 ± 98	783 ± 216
Atlantic mackerel	3	250 - 390	320 ± 70	363 ± 228
Atlantic menhaden	2	250	250	454
Sand lance	2	146 - 164	155 ± 13	8 ± 2
Cunner	2	140 - 150	145 ± 7	452 ± 3
Bluefish	1	250	250	1021
Atlantic saury	1	250	250	1
Four-beard rockling	1	250	250	43
Snake blenny	1	230	230	8
Yellowtail flounder	1	150	150	60
American plaice	1	140	140	19

Most prey items had been swallowed whole. I found very little evidence of biting and tearing off pieces of prey. One stomach contained two headless gadids (30-50 cm total length). The same stomach had an additional whole cod and two fresh ocean pout (*Macrozoares americanus*). The size of fish stomachs inside the seal stomach were very small in comparison to the seal stomach and contained small bivalves, crustaceans, amphipods, polychaetes, and plankton. Therefore, contamination from secondary ingestion was negligible. The wet weight of the stomach contents averaged 409 g, with a maximum of 1456 g. The regressed content weight per seal averaged 1007 g, with a maximum of 3893 g. This average closely agrees with Boulva and McLaren (1979), whose estimated meal size of 4% of body weight for small harbor seals would predict a regressed meal weight of 962 g.

Silver hake was the most important prey item by all four measures of prey importance dominating the diet from 40.8 %*M* to 70.6 %*F* (Table 5). The top five prey species included silver hake, red/white hake, Atlantic cod, squid, and redfish. The IRI values for silver hake ranked first and dominated in all measures of prey importance among the population sampled (Table 5). Each measure ranked the second most important species differently as either redfish (using percent number), or Atlantic cod (using percent mass), or squid (using percent frequency), and red/white hake (using IRI). Harbor seals were eating many small redfish ($\%N > \%M$), whereas they consumed fewer, more voluminous cod ($\%N < \%M$). Squid was rated higher with %*F* than the other measures of food importance, probably due to an increased retention time of beaks in the stomachs. Red/white was as equally important numerically as it was volumetrically (Table 5).

Table 5. Four measures of prey importance and rankings, listed by percent number, percent mass, percent frequency, and the index of relative importance for the top 11 prey species from the stomach contents of 68 harbor seals caught in Gulf of Maine sink gillnets, 1991-1997.

Prey Species	% Number (Ranking)	% Mass (Ranking)	% Frequency (Ranking)	IRI [a] (Ranking)
Silver hake	52.1 (1)	40.8 (1)	70.6 (1)	6558.7 (1)
Red and white hake	10.3 (3)	9.8 (3)	30.9 (3)	621.1 (2)
Atlantic cod	6.4 (5)	14.3 (2)	26.5 (4)	548.6 (3)
Squid	7.1 (4)	8.9 (4)	33.8 (2)	540.8 (4)
Redfish	11.5 (2)	3.9 (6)	20.6 (5)	317.2 (5)
Atlantic herring	3.7 (7)	6.0 (5)	19.1 (6)	185.3 (6)
Pollock	4.2 (6)	3.9 (7)	17.7 (7)	143.4 (7)
Ocean pout	1.4 (8)	1.5 (11)	7.4 (9)	na[c]
Alewife	0.5 (10)	1.8 (8)	11.8 (8)	na[c]
Flounder, mixed [b]	0.6 (9)	1.8 (9)	5.9 (10)	na[c]
Atlantic mackerel	0.3 (11)	1.6 (10)	5.9 (11)	na[c]

[a] IRI = index of relative importance.

[b] Flounder, mixed: includes winter flounder, American plaice, and yellowtail flounder.

[c] Not applicable due to low measures. Ranking becomes unreliable for any food types comprising <1% by the component methods.

The species richness was the highest in summer in the northern region, with the consumption of 16 prey species; however, 13 prey species in winter in the southern region diets were more evenly distributed. Silver hake, squid, red/white hake, Atlantic cod, pollock, and alewife (*Pomolobus pseudoharengus*) were consumed in all regions and seasons. Silver hake remained the most important across all areas and seasons. In the north, during the summer months, seals used relatively less squid and more redfish.

A small amount of cod was consumed in the northern-winter, eaten most frequently in the northern-summer, however became most important (in relation to number of other prey items) in the southern-summer. Flounder was not used in the southern summer. Atlantic herring was consumed only in the northern region, whereas alewife was eaten mostly in the southern region. Atlantic mackerel (*Scomber scombrus*) was consumed only during winter months.

Table 6. Percent frequency of occurrence by region and season. List of all prey species for 68 harbor seals taken in Gulf of Maine sink gillnets, in geographical and seasonal groupings, using percent frequency of occurrence, 1991-1997.

Prey Species	North/Summer (n=32)	North/Winter (n=22)	South/Summer (n=5)	South/Winter (n=9)
Silver hake	75.00	72.73	80.00	44.44
Redfish	40.63	0	0	11.11
Atlantic cod	34.38	4.55	60.00	33.33
Red and white hake	31.25	27.27	60.00	22.22
Pollock	15.63	18.18	20.00	22.22
Atlantic Herring	12.50	40.91	0	0
Squid, mixed	9.38	63.64	40.00	44.44
Ocean pout	6.25	0	0	33.33
Butterfish	3.13	0	0	0
Sand lance	3.13	0	0	11.11
Atlantic saury	3.13	0	0	0
Alewife	3.13	4.55	60.00	33.33
Four-beard rockling	3.13	0	0	0
Snake blenny	3.13	0	0	0
Cunner	3.13	4.55	0	0
Winter flounder	3.13	0	0	11.11
Atlantic mackerel	0	9.09	0	22.22
Atlantic menhaden	0	0	0	11.11
Yellowtail flounder	0	0	0	11.11
Atlantic wolffish	0	9.09	0	0
American plaice	0	4.55	0	0
Bluefish	0	4.55	0	0

Comparison of fish taken by harbor seals and sink gillnets

Landings from nets that also caught seals in my sample totaled 22,284 kg and the ingested weight from the seal stomachs totaled 68 kg. Harbor seals ate 11 of 22 commercial fish species landed. Rankings of fish biomass in the diets' of seals were significantly different from the rankings of the fish biomass that were landed from the same nets (Mann-Whitney U-test, $0.05 < P(U_{(2),13,15}) < 0.10$). Landings were dominated by spiny dogfish and seal diets were dominated by silver hake.

Calculation of the odds ratio and Chi-square on net catch and consumed fish showed a statistically significant positive selection by harbor seals on silver hake ($O = +2.49$), Atlantic herring ($O = +1.47$), red and white hake ($O = +1.30$), pollock ($O = +0.91$), redfish ($O = +0.43$), and Atlantic cod ($O = +0.32$) ($0.05 < P < 0.10$) (Table 7). Pollock and Atlantic cod were consumed in similar amounts; however, Atlantic cod was more than three times as abundant in the catch; therefore, harbor seals selected pollock over Atlantic cod. Dogfish, monkfish, bluefish (*Pomatomus saltatrix*), and skates (*Raja* spp.) were selected against by harbor seals. Fish species that were caught in the net and were not present in the seal diets yielded a negative selection and included: American lobster, witch flounder (*Glyptocephalus cynoglossus*), sea raven (*Hemitripterus americanus*), summer flounder (*Paralichthys dentatus*), sculpin (*Myoxocephalus octodecimspinosus*), cusk (*Brosme brosme*), haddock, windowpane flounder (*Lophopsetta maculata*), and four spot flounder (*Paralichthys oblongus*). Species that were caught in nets and occurred rarely in stomach contents, also resulted in a negative selection, including: winter flounder, Atlantic wolffish (*Anarhichas lupus*), American plaice, Atlantic mackerel, yellowtail flounder, and cunner (*Tautogolabrus adspersus*). Squid and ocean pout were eaten by seals and were not present in gillnets, resulting in a positive selection.

The average prey size, among taxa, of the harbor seal was 222 mm, ranging from 50 mm to 500 mm (Table 4). The smallest and largest fish eaten were silver hake. Small prey (under 100 mm) included silver hake, redfish, red and white hake, Atlantic cod, pollock, and butterfish (*Peprilus triacanthus*). Large prey (over 350 mm) included silver hake, red and white hake, Atlantic cod, ocean pout, Atlantic wolffish, and Atlantic mackerel.

Fish consumed by seals were smaller than the catch discarded, which in turn were smaller than the catch kept by the fishermen (Figures 5 to 9). There was little to no overlap of fish size between seal prey and commercially targeted fish. Some overlap was seen with silver hake (Figure 5), however the kept sample size was very small as silver hake was rarely kept at all. There was a highly significant size difference between gillnet catch and seal prey size at $P < 0.0001$, where seals are selecting smaller individuals.

Table 7. Odds ratio with proportions of mass caught in GOM sink gillnets and proportions of mass in harbor seal diets taken from the same nets (n = 22), 1991 - 1997.

Species	Percent Mass In Net	Percent Mass Consumed	Log_{10} Odds Ratio
Spiny dogfish	82.58	0.00	-
Silver hake	0.24	42.29	+2.49
Red and white hake	1.21	19.41	+1.30
Squid	0.00	17.13	+
Atlantic cod	3.97	7.90	+0.32
Pollock	1.06	7.97	+0.91
Monkfish	5.35	0.00	-
Atlantic herring	0.09	2.68	+1.47
Ocean pout	0.00	2.54	+
Bluefish	1.88	0.00	-
Skate	1.81	0.00	-
American lobster	0.54	0.00	-
Witch flounder	0.31	0.00	-
Sea raven	0.25	0.00	-
Winter flounder	0.21	0.00	-
Summer flounder	0.16	0.00	-
Redfish	0.03	0.08	+0.43
Sculpin	0.10	0.00	-
Atlantic wolffish	0.06	0.00	-
American plaice	0.04	0.00	-
Atlantic mackerel	0.03	0.00	-
Yellowtail flounder	0.03	0.00	-
Cusk	0.03	0.00	-
Haddock	0.02	0.00	-
Windowpane flounder	0.01	0.00	-
Fourspot flounder	0.01	0.00	-
Cunner	0.01	0.00	-

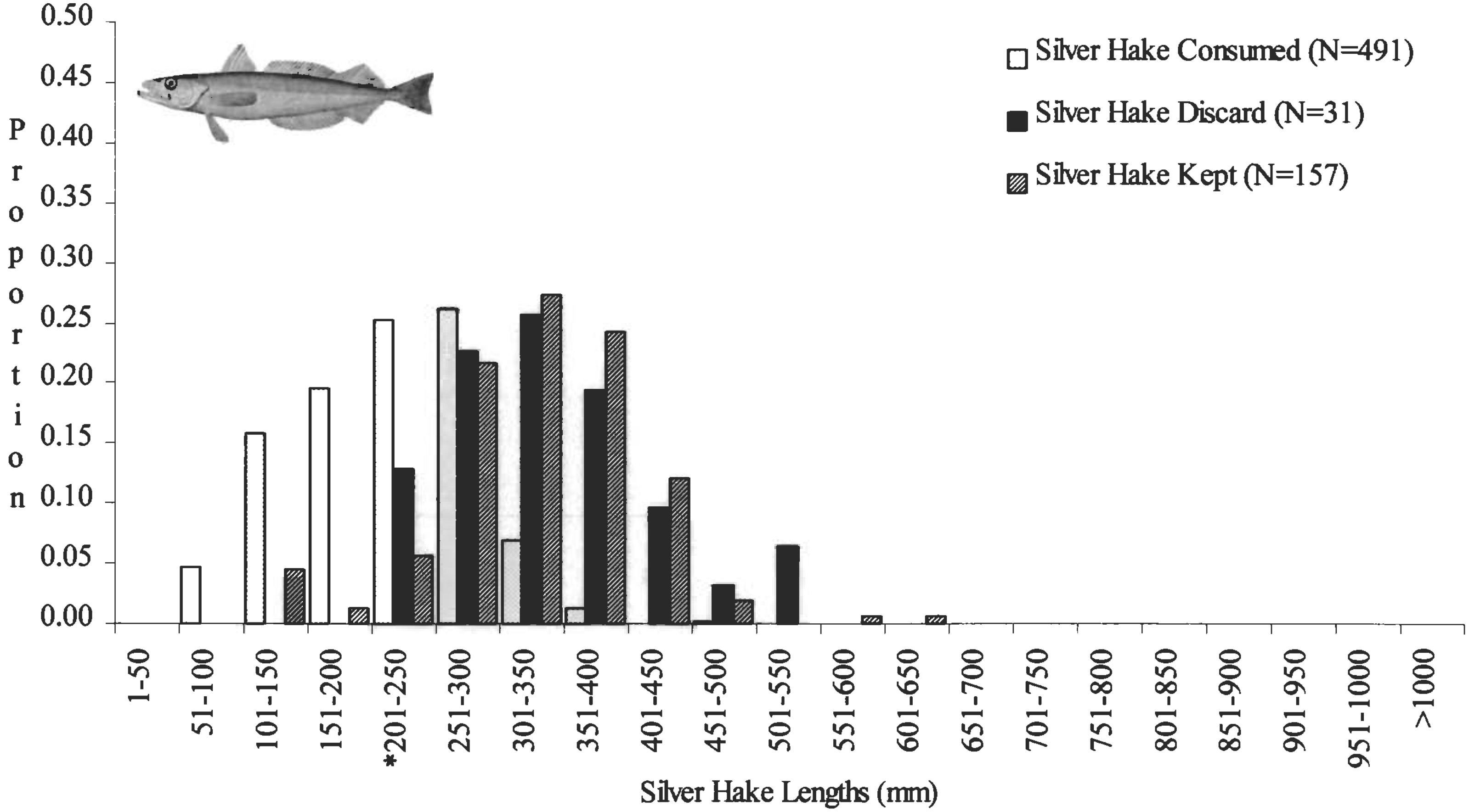

Figure 5. Length frequency distribution of silver hake consumed by 75 harbor seals, discarded and kept by commercial fishermen in the Gulf of Maine sink gillnet fishery, 1991 - 1997. *Size at 50% maturity is 227 mm (Clark 1998).

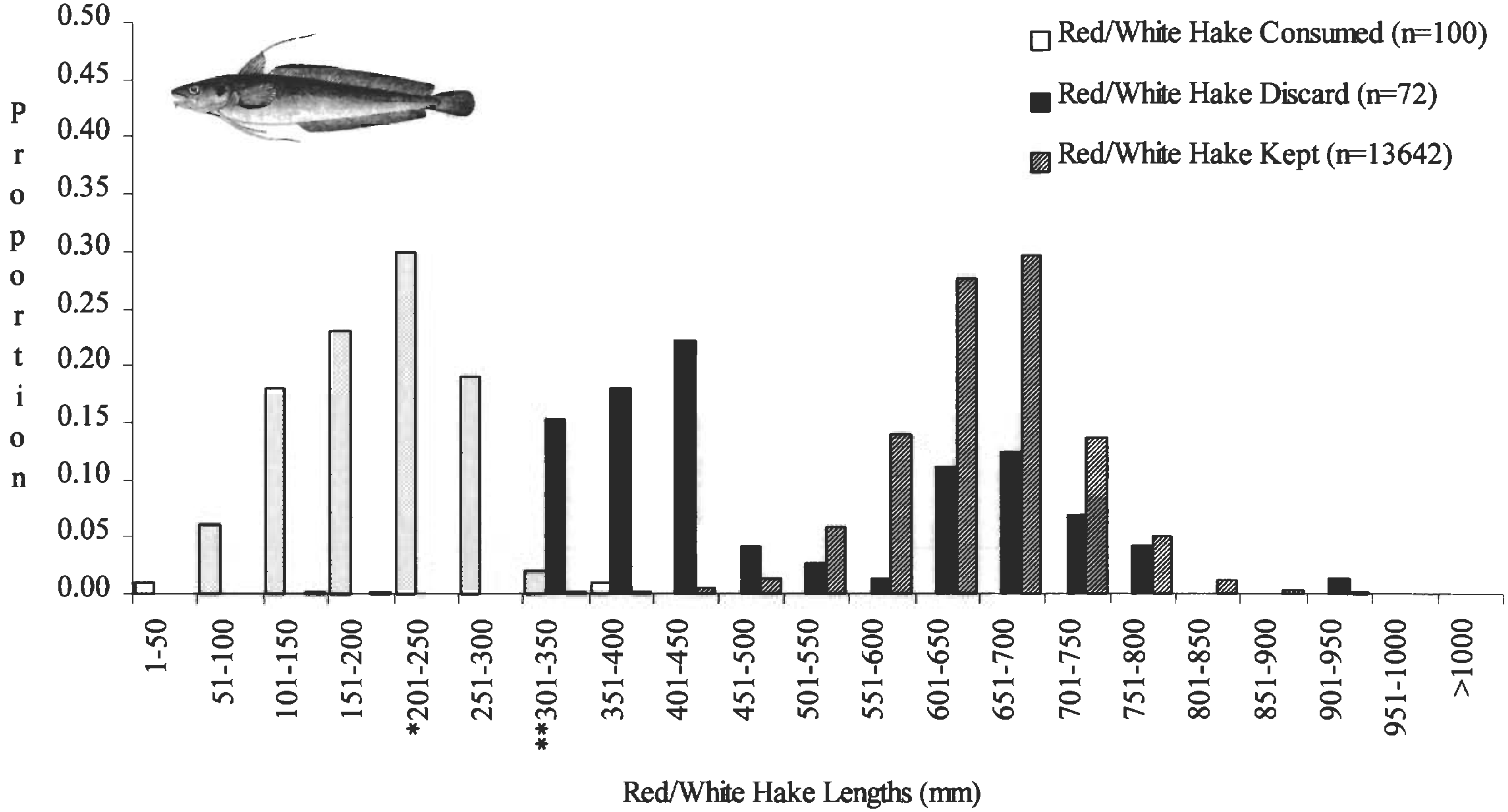

Figure 6. Length frequency distribution of red and white hake consumed by 75 harbor seals, discarded, and kept by commercial fishermen in the Gulf of Maine sink gillnet fishery, 1991 - 1997. *Size at 50% maturity for red hake is 245 mm (Clark 1998). **Size at 50% maturity for white hake is 339 mm (Clark 1998).

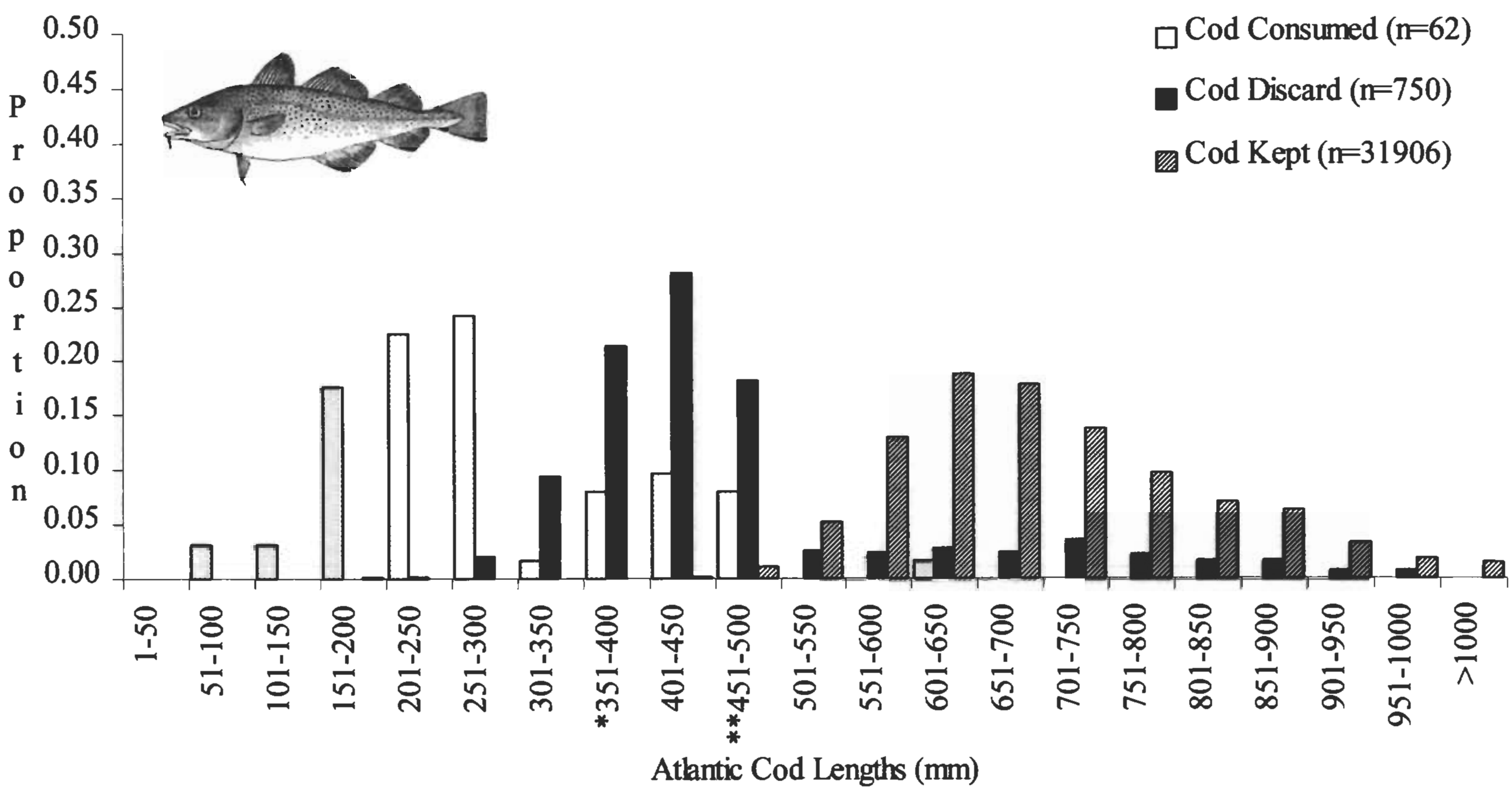

Figure 7. Length frequency distribution of Atl. cod consumed by 75 harbor seals, discarded and kept by commercial fishermen in the Gulf of Maine sink gillnet fishery, 1991 - 1997. *Size at 50% maturity is 355 mm (Clark 1998). **Legal size limit is 483 mm (Federal Register 1998).

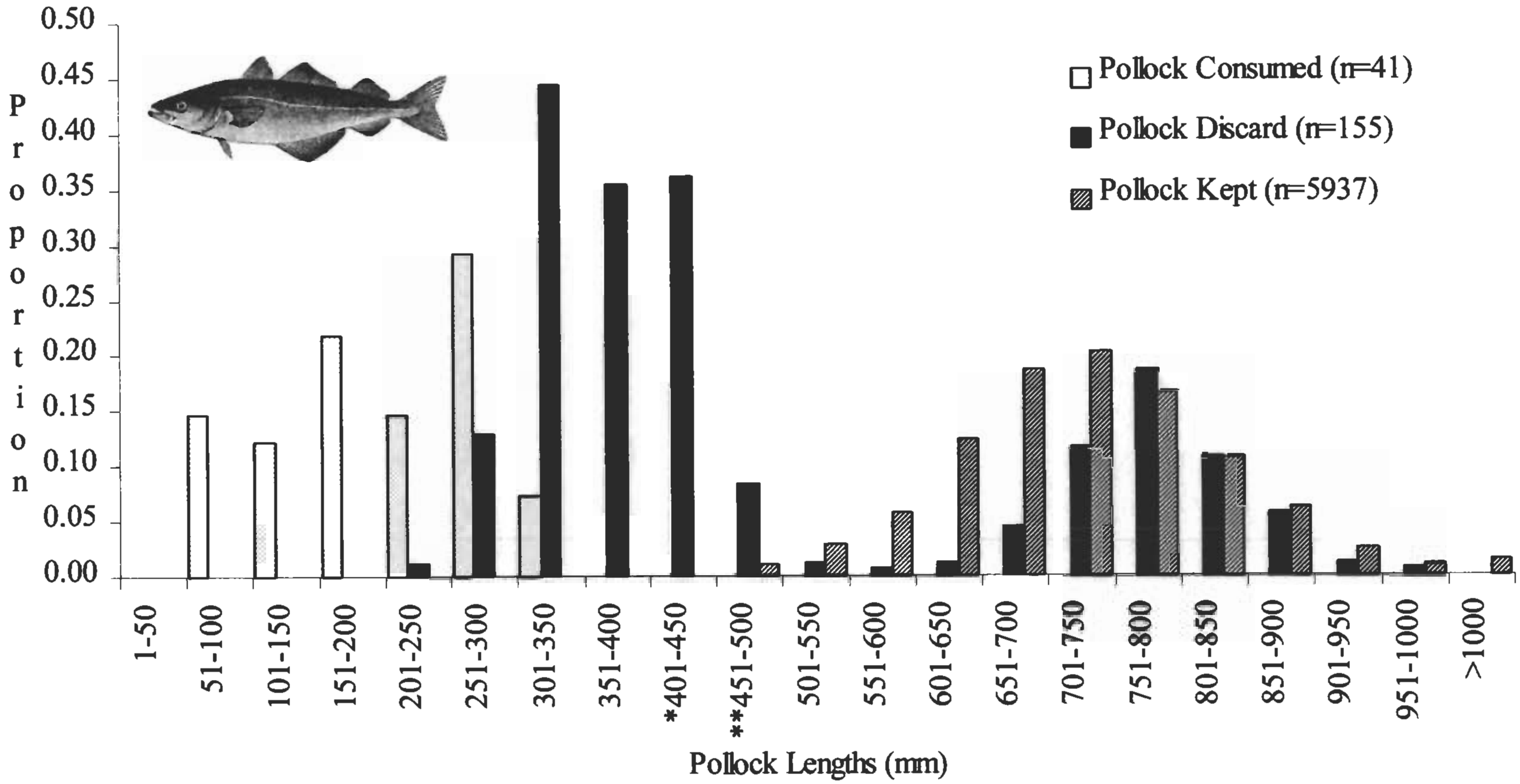

Figure 8. Length frequency distribution of pollock consumed by 75 harbor seals, discarded and kept by commercial fishermen in the Gulf of Maine sink gillnet fishery, 1991 - 1997. *Size at 50% maturity is 405 mm (Clark 1998). **Legal size limit is 483 mm (Federal Register 1998).

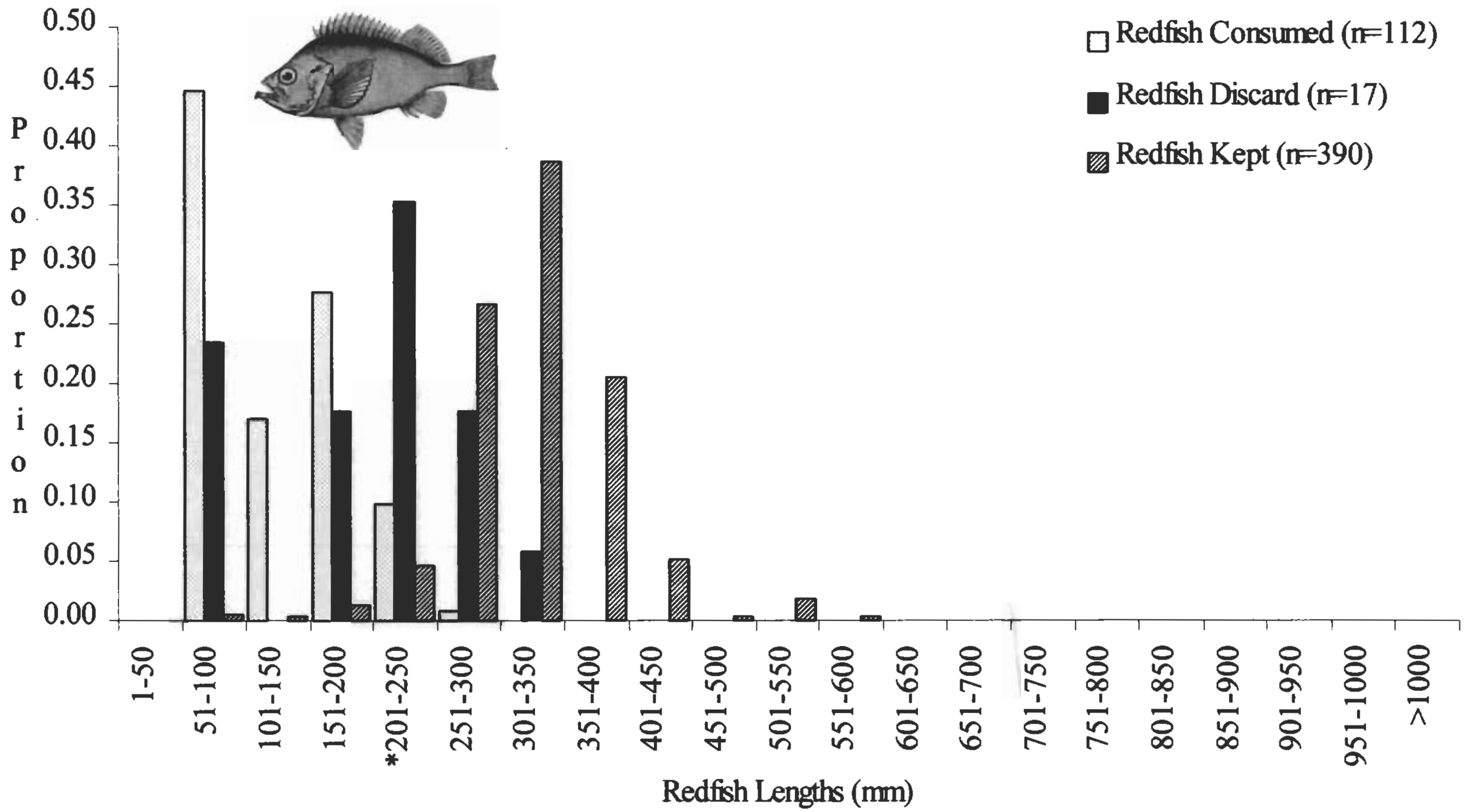

Figure 9. Length frequency distribution of redfish consumed by 75 harbor seals, discarded and kept by commercial fishermen in the Gulf of Maine sink gillnet fishery, 1991 - 1997. *Size at 50% maturity is 215 mm (Clark 1998) and legal size limit is 229 mm (Federal Register 1998).

The number of stomach samples collected from each of the sub-fisheries was 26 (2 of which were empty) in mixed groundfish nets, 25 (1 of which was empty) in monkfish nets, 14 (4 of which were empty) in dogfish nets, and 10 (0 empty) in mixed flounder nets. Of the seals caught in groundfish nets 33% had groundfish present in their stomachs, 20% of the stomachs from flounder nets had flounder present, and no seals had eaten dogfish or monkfish.

The relative stomach fullness index (SFI) of my sample averaged 56.8%. The average SFI of seals caught in dogfish nets was 45.5%, groundfish nets was 49.7%, monkfish nets was 62%, and flounder nets was the fullest at 69.2%. Figure 10 illustrates the SFI in each of the sub-fisheries by three fullness categories. Most of the seal stomachs that were completely empty were obtained in dogfish nets (29% of the seals from dogfish nets had no food remains), whereas no stomachs were completely empty in flounder nets.

Silver hake had the highest percent frequency of occurrence across all sub-fisheries (Figure 11). When caught in groundfish nets, the seals primarily fed on silver hake, Atlantic cod, and redfish. Seals from the monkfish nets primarily fed on silver hake, squid, red/white hake, and Atlantic herring. In the flounder nets, seals had eaten silver hake, Atlantic cod, and Atlantic herring. In the dogfish nets, seals had eaten silver hake, red/white hake, squid, Atlantic cod, and redfish.

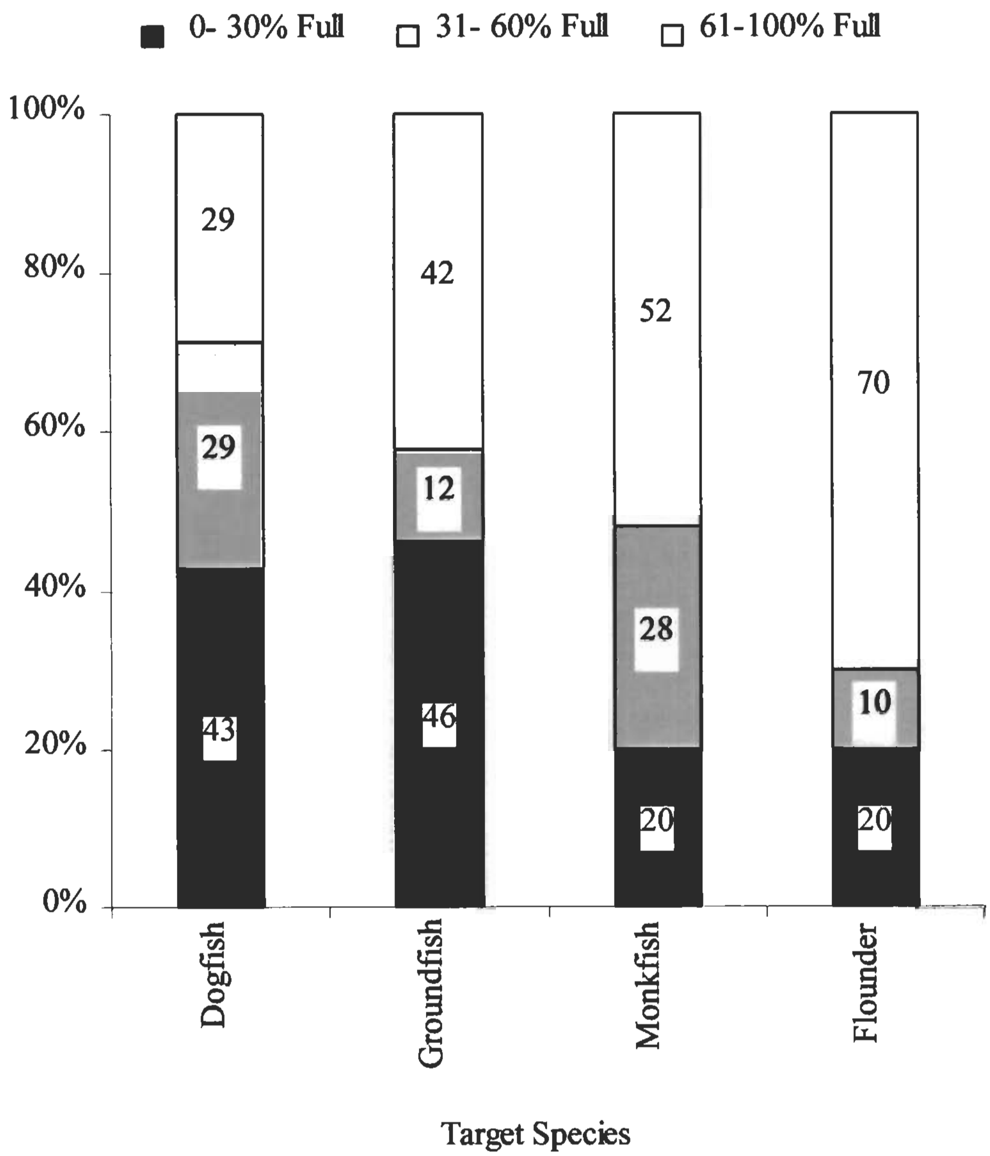

Figure 10. Average stomach fullness (relative SFI) for harbor seals (n = 75) caught in four sink gillnet sub-fisheries in the Gulf of Maine, 1991 - 1997.

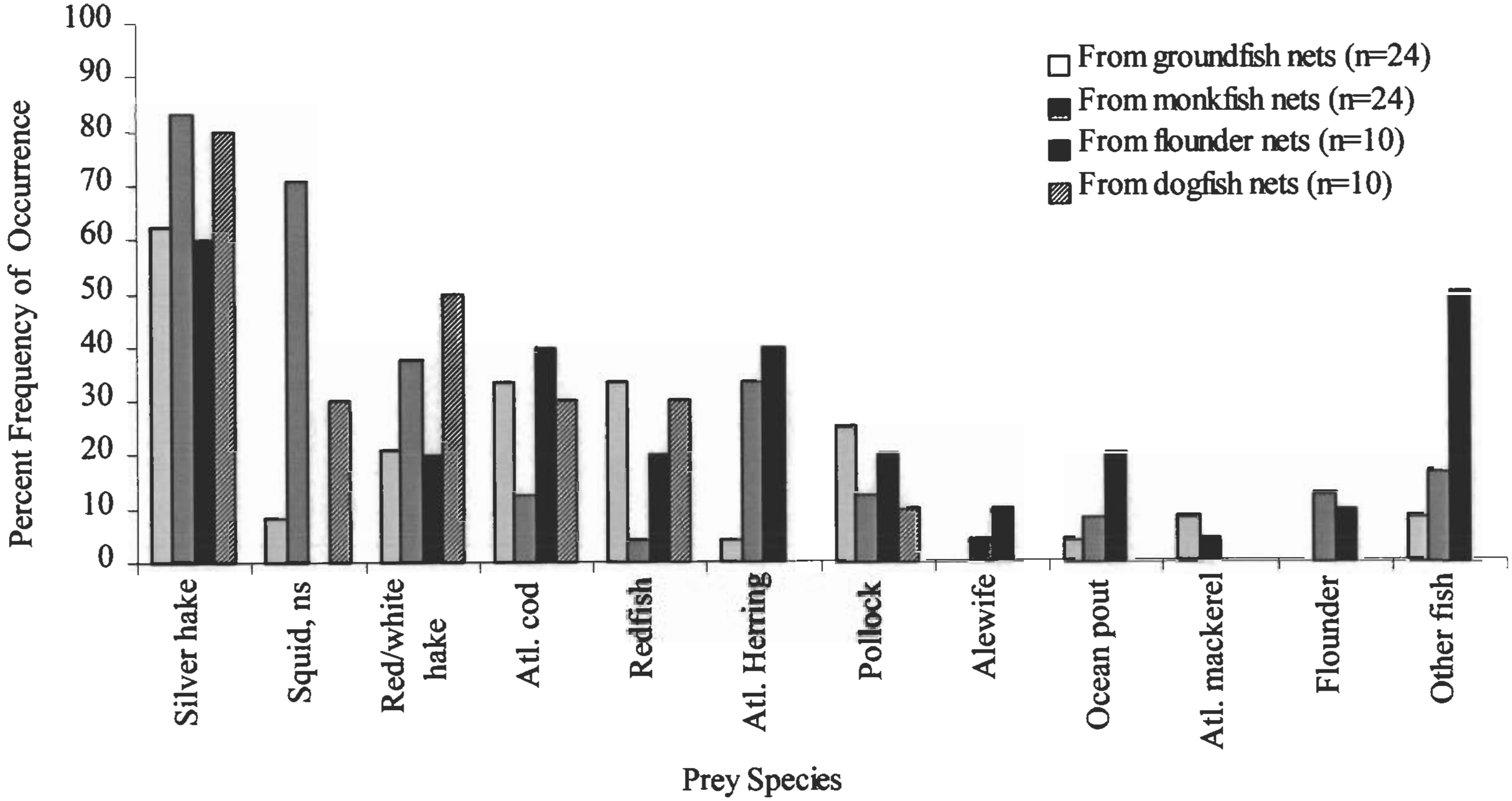

Figure 11. Percent frequency of occurrence from 68 non-empty harbor seal stomachs for four sink gillnet sub-fisheries, 1991-1997. No evidence of dogfish, monkfish, or lobster was found in the stomachs. Flounder includes: winter flounder, American plaice, and yellowtail flounder. Other fish includes: Atl. wolffish, cunner, sand lance, Atl. menhaden, Atl. saury, bluefish, butterfish, four-beard rockling, and snake blenny.

Of the 13,783 sink gillnet hauls that were observed for discards, 2% of the hauls had fish discards allegedly resulting from seal damage. When it occurred, the fish damaged by seals within a haul ranged from 1 to 21 kilograms. Damage by seals consisted of pollock (75%), Atlantic cod (13%), bluefish (8%), white hake (2%), American shad (*Pomolobus mediocris*) (<1%), monkfish (<1%), haddock (<1%), silver hake (<1%), Atlantic mackerel (<1%), red hake (*Urophycis chuss*) (<1%), tautog (*Tautoga onitis*) (<1%), American plaice (<1%), yellowtail flounder (<1%), and winter flounder (<1%). Pollock and bluefish had the highest rate of damage per haul. Ninety percent of the observed seal damage was recorded between the months of August and December (with only 49% of the observer coverage occurred within those months).

Discards due to seal damage totaled 3% of the discarded pollock, Atlantic cod, bluefish, white hake, American shad, monkfish, haddock, silver hake, Atlantic mackerel, red hake, tautog, American plaice, yellowtail flounder, and winter flounder. In comparison, 41% of the discards were due to market or regulations, 27% due to hagfish damage, 19% due to sand flea damage, and 10% due to overall poor quality. Discards due to regulations occurred most frequently, averaging 6.8 kg per haul, for those fish species. Although seal damage occurred infrequently, but when it did occur it averaged 17 kg per haul. When pollock or bluefish was damaged by seals, it averaged 21 kg per haul.

Discussion

The ratio of pups and juvenile harbor seals to adults caught in gillnets was considered high. Ninety three percent of the harbor seal takes in sink gillnets were less than 4 years old, the oldest of 8 years old. Harbor seals may live up to 30 years and reach lengths of 161 cm (Bigg 1969). Harbor seals caught in gillnets were small, averaging 102 cm in total length. Young seals had a higher probability of becoming entangled in gillnets than adults. I have considered several possible explanations. Adult harbor seals may be more adept at avoiding or escaping gillnet entanglements than juveniles and pups. There may be an effect of spatial segregation based on age where the relative abundance of young may be greater on gillnet fishing grounds. However, not enough is known about age segregated elements of the harbor seal population in this study area to explain the differences in entanglement rates. Juveniles may be restricted to shallow water and frequent the waters where gillnetting occurs more than adults. Juveniles make shallower dives than adults and have a lower foraging success rate (Lesage *et al. in prep*). Adult seals are less restricted by water depth and distance to shore and therefore have a larger foraging area. The difference may also stem from timing of sampling due to favorable weather conditions relative to seal weaning. The observers' rate of sampling seals was higher in July (86 percent), when most pups have just weaned, than in other months (53 percent). Juvenile seals may actually benefit from foraging near gillnets if potential predators, such as sharks, ignore them because of alternate food sources.

Stomachs collected from accidental entanglements of seals in gillnets provided large, fresh samples that were excellent for dietary studies. Pierce *et al.* (1991) found significantly more food remains when they included the intestines and colon with the stomach sample. I encourage observers and pinniped necropsy groups to collect the entire digestive tract to maximize sampling of incidental catches of marine mammals. Of my sample, 91% had food remains, whereas in other studies that intentionally killed seals to obtain digestive tract samples only 53% to 61% of the retrieved seals had food in their stomachs (Bowen and Harrison 1996, Pierce *et al.* 1991). Rae (1960) had found a high proportion of empty stomachs of seals caught in salmon nets and attributed the absence of food remains to vomiting induced by fear. I found no evidence of vomiting or regurgitation when seal by-catch was brought in whole. In comparison to other studies, my samples seemed full and fresh. Although stomachs collected from seals caught in fishing gear may introduce biases, it is still a valuable source of information on the foods of seals that should not be overlooked.

Jobling and Breiby (1986) found that most seals alternate between periods of feeding and resting so remains recovered from stomachs represent not more than one day of consumption. Thus, preferential retention of large indigestible remains with gradual accumulation is not likely. Prime (1979) found that the time of passage of otoliths, i.e. time between ingestion and egestion, for a harbor seal in captivity ranged from 6 hours 30 minutes to 29 hours 45 minutes. Markussen (1993) conducted a study of transit time of digesta in captive seals and found that seal stomachs started to empty within an hour of the meal and some prey remained for 5 hours. Murie and Lavigne (1986) found a longer digestion time, recovering all otoliths after 3 hours and 70% of ingested otoliths in seal stomachs 6 hours after a meal. Based on the state of digestion in the stomachs of my study, including the proportion of otoliths in skull cases and volume of intact fish, the contents were probably ingested between 0 and 6 hours prior to death. Murie and Lavigne (1986) warn that consumption of fish with small otoliths would be underestimated if stomachs were collected more than 3 hours after the seals ate. Food items that are digested quickly will be quantitatively underestimated by stomach-content analysis (Markussen 1993); however, the stomach samples in my study showed good state of preservation of otoliths and severely eroded otoliths were not used in my analysis. da Silva and Neilson (1985) measured the dissolution of otoliths of prey species of harbor seals and provided a rank order based on surface area to volume ratios of otoliths. Mackerel, herring, and ocean pout having small otoliths would have a faster dissolution rate than flounder, silver hake, redfish, pollock, cod, and haddock (in rank order) (da Silva and Neilson 1985). Their study was based on scat analysis, where digestion of otoliths will result in more biases than with fresh gut contents. Although unlikely, my study may have under-represented smaller mackerel and herring and over-represented larger cod and pollock in the diets of harbor seals.

Each method of measuring the relative importance of food types has their limitations. The measure of frequency of occurrence tends to exaggerate the importance of incidental prey items (Pierce and Boyle 1991). It treats a food item of same importance whether the predator ate one or many prey individuals, so food items that are eaten frequently but in small quantities may be over-emphasized. Items that were rarely eaten could still have a high percent frequency of occurrence. For example, butterfish and Atlantic saury were eaten by one seal each (%*F*=1.47) having the same importance even though 5 butterfish were eaten over 1 saury (Table 4). Food items that have longer retention will be over-counted because of the longer amount of time that it is in the stomach. Squid beaks remain in the stomach longer than fish (Bigg and Perez 1985). This bias is demonstrated by the increased importance of squid when using frequency of occurrence (Table 5). Percentage count or number will also over-represent species with longer retention and under-represent the number of individuals that are digested faster. Numerical estimates overemphasize the importance of small prey items taken in large numbers (Hyslop 1980). Bigg and Perez (1985) and Gannon *et al.* (1997*b*) suggested performing analysis on trace (well-digested remains of hard parts) counts and non-trace (remains with soft tissue) counts separately for animals that eat both squid and fish. I did not include any well-digested otoliths or squid beaks in an attempt to reduce the bias of differing retention and digestion rates. Percent mass will under-represent items that are quickly digested but is considered the most direct measure of prey importance (Bigg and Perez 1985). This measure may over-emphasize the importance of single large prey-items (Hellawell and Abel 1971). Percent mass also introduces a degree of error in the regression equations used to estimate fish size at ingestion. By incorporating all three measures, the IRI could cancel or compound various biases of each component (Bigg and Perez 1985, Hyslop 1980, Pierce and Boyle 1991). It may underestimate food types with components < 1%, such as alewife, flounder, and Atlantic mackerel (Bigg and Perez 1985). My study may overemphasize the importance of squid and redfish and underestimate the importance of herring, however it would not change the overall IRI rankings. Taking all the biases into account, my data are probably best represented by the percent frequency measures.

From the species composition within and among samples, young harbor seals do appear to feed opportunistically on few large demersal fish and selectively on small pelagic fish and cephalopods. The diets of seals changed both seasonally and geographically suggesting they are primarily opportunistic feeders. The only other published study of the food habits of harbor seals in southern New England (New Hampshire to Long Island Sound) found sand lance (*Ammodytes americanus*) was the dominant prey item, based on frequency of occurrence in scat samples (Payne and Selzer 1989). They reported regional, seasonal, and annual fluctuations in the diet. Sand lance was used most commonly in sandy bottom habitat off Cape Cod, whereas more rockfish and gadids were consumed in colder, rocky habitat off New Hampshire (Payne and Selzer 1989). I only found 2 stomachs, with one sand lance each, but sandy bottom habitat close to shore is not represented in my sample. Silver hake and pollock were abundant in my samples and absent in the scat samples. Payne and Selzer (1989) identified long-finned hake (*Urophycis chesteri*), haddock, and skates that weren't represented in my samples. My findings were similar to Hunt (1948, from Payne *et al.* 1985) who reported that herring and squid were the dominant prey species during the winter off Maine. I also found that Atlantic menhaden (*Brevoortia tyrannus*) and alewife were preyed on by harbor seals off Cape Cod, as in Allen (1942). In eastern Canada, Bowen and Harrison (1996) found that harbor seals, of less than 1 year old, fed on pelagic prey, such as herring and squid, whereas older seals preyed on more demersal and benthic prey. Bowen and Harrison (1996) found that Atlantic herring, Atlantic cod, pollock, and short-finned squid accounted for 72% of prey occurrence in harbor seals. Temporal and spatial changes in prey composition could be a result of migration of prey into and out of the area and distributional boundaries. However, this study was not designed to estimate total prey availability, which could be attempted by using research trawl data aimed at estimating fish distribution and abundance.

Commercial fish species of the GOM gillnet fishery are not significantly represented in the harbor seal diets. Diets of seals killed in fishing nets are expected to be biased towards fish present in nets (Pierce and Boyle 1991), but I found little resemblance between diet and catch composition. When looking at size distributions, there was almost no overlap between commercially targeted fish and harbor seal diets (Figures 5-9). Boulva and McLaren (1979) concluded that harbor seals have a negligible impact on fish stocks in eastern Canada. I similarly found that seals are principally feeding on groundfish that are juvenile pre-recruits to fisheries and therefore are not in direct competition with fishermen for the targeted fish. Small juvenile fish are of low reproductive value (Trippel 1998) and are not as important in rebuilding fish populations (Myers *et al.* 1995). My samples were mostly from juveniles and larger seals will eat larger fish; however, diet studies on larger seals indicate that the prey size is generally not greater than 35 cm (Bowen *et al.* 1993) and still below target size. Seals may be feeding on similar prey of the targeted fish (Bigelow and Schroeder 1953, Langton 1982) and the potential exists for resource competition between seals and commercially important fish. Harbor seals may be feeding on predators and competitors of commercially important species and may assist in the recovery of depleted stocks of higher valued fish.

The fullness of seal stomachs in flounder nets and the low occurrence of flounder in the stomachs suggests that harbor seals are finding above-average prey densities in areas with flounder nets, although are not necessarily feeding on flounders. The high presence of cod in the stomachs of seals caught in flounder gear and the low by-catch of cod demonstrates how selective the flounder gillnets can be in avoiding cod and other round groundfish. Fresh fish in seal stomachs is an indication that cod was present but not caught in nets, which is mostly a result of the floatline on flounder gear laying closer to the bottom (observer data). Since most of the stomachs were empty in dogfish nets, seals may be competing for food with dogfish.

Instances of fish damaged by seals is an indicator of diet but has many biases associated with it. Since the act of damaging fish is not witnessed, other marine mammals, fish, or sharks may be doing the damage. Most prey was consumed whole. Although seals did allegedly damage fish that were caught in gillnets, the loss was minimal when compared to the degree of discarding fish for other reasons. The heaviest seal damage occurred to patches of pollock in August and when pollock was the dominant catch within the string. I looked at the possible explanation for the seasonality of seal damage in relation to the spawning seasons of fish and higher nutritional requirements of pregnant or lactating seals. No patterns were found, in fact pollock spawns in December and January (Smith 1983). The amount of seal damage did not correlate with the number of harbor seal incidental takes, however biases are introduced from the conflicting sampling priorities of observing discarded catch and watching the net for incidental take fall outs. The probability of witnessing an incidental take decreases when fish discard information is being collected (Bravington and Bisack 1996), so one would predict the take rate to be lower during hauls with recorded catch damage. Observations of seal damage and other discard reasons are subject to observer interpretation and may be influenced by the individual's training, debriefing and prevalent concerns of the industry. I found sporadic use of discard reasons depending on the individual observer, year, port, and simultaneous research projects.

It should be recognized that this study reflects only the diets of juvenile harbor seals near gillnets. The seals in my sample have already made a selection of a feeding site, therefore inferences on a larger scale should be made with caution. If one resource is abundant, the use of that resource may appear low when compared to availability within the feeding site but higher when compared to the general area from which the feeding site was selected (Thomas and Taylor 1990). The catch from sink gillnets is also selective and does not reflect the total availability of resources in the area. However, the conclusions from this study are valid for food use and prey selection, relative to what fishermen catch, by juvenile harbor seals within gillnet fishing grounds.

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Biography

Amy Sierra Williams (maiden name Van Atten) was born in Worcester, Massachusetts. Her childhood years were spent in Australia and France before moving back to the United States in 1980. She graduated from Shrewsbury High School in 1987 after spending a year abroad in Zimbabwe. She studied music, dance, art, and languages and is active in community services for handicapped children. She attended the University of Massachusetts in Amherst and graduated in 1991 with a Bachelor of Science degree in Wildlife and Fisheries Biology. She spent several years working in Woods Hole for the National Marine Fisheries Service's observer program and Protected Species Branch before entering the Wildlife Ecology program at the University of Maine in the fall of 1995.

After receiving her degree, Amy will continue her position as research fishery biologist with the National Marine Fisheries Service in Woods Hole, Massachusetts. Her current project, in conjunction with the International Whaling Commission, will bring her to Chile and Antarctica. She is also an avid wildlife photographer and publishes her work in field guides. Amy is a candidate for the Master of Science degree in Wildlife Ecology from the University of Maine in December, 1999.