TROPHIC IMPORTANCE OF SOME MARINE GADIDS IN NORTHERN ALASKA AND THEIR BODY-OTOLITH SIZE RELATIONSHIPS

Natural marine ecosystems are being subjected to ever increasing human-induced stresses, including expanding commercial fisheries and activities associated with the exploration and development of offshore petroleum resources. Numerous studies of the food habits and trophic interactions of marine vertebrate consumers have been undertaken in Alaska during the last 5 yr in response to increased demand for multispecies approaches in fishery management plans and the legal requirement for environmental assessments prior to petroleum development. Through these and other studies the importance of three species—walleye pollock, *Theragra chalcogramma*, saffron cod, *Eleginus gracilis*, and Arctic cod, *Boreogadus saida*—in Arctic and subarctic ecosystems has become increasingly apparent (Klumov 1937; Andriyashev 1954; Lowry and Frost in press; Pereyra et al.[1]). These species are widespread and locally abundant, are major secondary consumers, and are important prey of other species (Table 1).

Walleye pollock are found throughout the North Pacific and in greatest abundance along the continental shelf break of the Bering Sea. Abundance decreases rapidly north of St. Matthew Island, and they are caught only rarely north of Bering Strait (Pereyra et al. footnote 1). The species supports a commercial fishery of almost 1 million t annually, one of the largest in the world. Walleye pollock form a major portion of the diet of all pinnipeds in the southern Bering Sea, except bearded seals and walruses, and are eaten by at least 4 species of cetaceans, 13 species of seabirds, and 10 species of fishes in that area.

Saffron cod occur in the eastern Bering and Chukchi Seas and throughout the western Arctic Ocean (Andriyashev 1954). They are also present, but less abundant, in the Beaufort Sea. Saffron cod are utilized for food by coastal Eskimos. They make up a major portion of the diet of ringed and spotted seals and white whales in the northern Bering and southern Chukchi Seas. They are also

[1]Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Processed rep., 619 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard E., Seattle, WA 98112.

TABLE 1.—Marine mammals, birds, and fishes reported to eat walleye pollock, saffron cod, and Arctic cod.

Species	Walleye pollock	Saffron cod	Arctic cod
Marine mammals:			
Northern fur seal, *Callorhinus ursinus*	9		
Steller sea lion, *Eumetopias jubatus*	3, 10, 31		
Pacific harbor seal, *Phoca vitulina richardsi*	23, 24, 31		
Spotted seal, *P. largha*	22, 23, 31	32	22, 23
Ribbon seal, *P. fasciata*	14, 23, 31	14, 23	22, 23
Ringed seal, *P. hispida*	32	11, 23	2, 6, 11, 23
Bearded seal, *Erignathus barbatus*	31, 32	8, 23	2, 11, 32
Fin whale, *Balaenoptera physalus*	5, 13	5	1, 5
Minke whale, *B. acutorostrata*	5, 25	5	1, 5
Sei whale, *B. borealis*	5		5
Humpback whale, *Megaptera novaengliae*	5	5	1, 5
White whale, *Delphinapterus leucas*		5, 25	1, 2, 25
Harp seal, *Phoca groenlandica*			1
Narwhal, *Monodon monocerus*			1, 2, 18
Harbor porpoise, *Phocoena phocoena*		25	
Polar bear, *Ursus maritimus*			1
Birds:			
Glaucous gull, *Larus hyperboreus*	20		12
Herring gull, *L. argentatus*			12
Sabine's gull, *Xema sabini*			15
Ross's gull, *Rhodostethia rosea*			17
Ivory gull, *Pagophila eburnea*	20		17
Black-legged kittiwake, *Rissa tridactyla*	20, 21	30	1, 12, 30
Red-legged kittiwake, *R. brevirostris*	20, 21		
Common murre, *Uria aalge*	16, 21	30	7, 21, 30
Thick-billed murre, *U. lomvia*	16, 21	30	7, 28, 30
Black guillemot, *Cepphus grylle*	20		1, 12, 28
Pigeon guillemot, *C. columba*			12
Tufted puffin, *Lunda cirrhata*	21		12
Horned puffin, *Fratercula corniculata*	21		12
Kittlitz's murrelet, *Brachyramphus brevirostre*			15
Parakeet auklet, *Cyclorrhynchus psittaculus*	21		15
Least auklet, *Aethia pusilla*	21		
Arctic tern, *Sterna paradisea*			4
Fulmar, *Fulmarus glacialis*	21		28
Shearwaters, *Puffinus* spp.			15
Pelagic cormorant, *Phalacrocorax pelagicus*			12, 15
Red-faced cormorant, *P. urile*	21		
Red-throated loon, *Gavia stellata*			15, 19
Jaegers, *Stercorarius* spp.			1
Fishes:			
Atlantic cod, *Gadus morhua*			1
Pacific cod, *G. macrocephalus*	4, 26, 32		
Walleye pollock, *Theragra chalcogramma*	26, 32		
Saffron cod, *Eleginus gracilis*		4	4
Pacific halibut, *Hippoglossus stenolepis*	29		
Greenland halibut, *Reinhardtius hippoglossoides*	26, 32		
Sablefish, *Anoplopoma fimbria*	26		
Flathead sole, *Hippoglossoides elassodon*	29, 32		
American plaice, *H. platessoides*			1
Arrowtooth flounder, *Atheresthes stomias*	26, 29		
Snailfish, *Liparis* sp.	32		
Eelpout, *Lycodes* spp.	32		
Sculpins, *Icelus spiniger*, *Myoxocephalus* spp.	32	32	
Sheefish, *Stenodus leucichthys*		32	
Arctic char, *Salvelinus alpinus*		32	27, 28
Atlantic salmon, *Salmo salar*			1

1. Klumov 1937
2. Vibe 1950
3. Wilke and Kenyon 1952
4. Andriyashev 1954
5. Tomilin 1957
6. McLaren 1958
7. Tuck 1960
8. Kenyon 1962
9. Fiscus et al. 1964
10. Fiscus and Baines 1966
11. Johnson et al. 1966
12. Swartz 1966
13. Nemoto 1970
14. Fedoseev and Bukhtiyarov 1972
15. Watson and Divoky 1972
16. Ogi and Tsujita 1973
17. Divoky 1976
18. Mansfield et al. 1975
19. Bergman and Derksen 1977
20. Divoky in press
21. Hunt et al. in press
22. Frost and Lowry 1980
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prey of other cetaceans and numerous birds and fishes.

Arctic cod are circumpolar in Arctic waters extending south to at least lat. 60° N on the Alaska coast, typically in association with sea ice (Andriyashev 1954). They are a species of key trophic importance upon which many other far northern marine consumers depend entirely for a major portion of their yearly nutritional requirements. They are eaten by at least 12 species of marine mammals, 20 species of birds, and 5 species of fishes. Arctic cod are especially important because in the areas and at the times when they are abundant they are the only forage fishes present.

Investigations of food habits of marine animals almost invariably involve analysis of stomach contents. Morrow (1979) published preliminary keys to otoliths of 16 families of fishes found in Alaskan waters including the Gadidae, whereby fishes eaten by predators can be identified from otoliths even after soft parts and bones have been digested. In most instances the size of the fish or meal can also be determined from otoliths through back calculation of fish length and/or weight from various measurements of otolith size (Morrow 1951; Templeman and Squires 1956; Southward 1962; Gjosaeter 1973).

In this paper we present relationships of otolith length to fish length and weight for pollock, saffron cod, and Arctic cod of the Bering, Chukchi, and Beaufort Seas.

Methods

Samples of fishes were obtained by otter trawling in the Bering, Chukchi, and Beaufort Seas (Table 2). Soon after capture all fishes were identified, weighed to the nearest 0.1 g, and fork length measured to the nearest millimeter. The sagittal otoliths were removed and length and width measured to the nearest 0.1 mm with vernier calipers.

When otolith lengths and widths were plotted against fish lengths as scatter diagrams, the relationship between otolith length and fish length was found to be less variable than that of otolith width and fish length. For this reason otolith length was taken as the criterion for otolith size and used in subsequent calculations. Casteel (1976) discussed in detail the reasons for using length as the best measure of otolith size.

We chose a double regression method for relating otolith size to fish size (Fitch and Brownell 1968; Casteel 1976). For each species the relationships of otolith length to fish length and fish length to fish weight were calculated. In cases where two equations were required to fit a single relationship, the inflection point was determined by iteration. The specified inflection point was varied by increments of 0.1 and the pair of equations which minimized the combined deviation was selected.

Results and Discussion

Regressions of fish fork length on otolith length differed markedly among the three species. Those of walleye pollock and saffron cod formed two distinct straight-line sections each, with inflection points at otolith lengths of 10 mm in walleye pollock (fish length 22 cm) and 8.5 mm in saffron cod (fish length 15 cm) (Figures 1, 2). The regression for Arctic cod was rectilinear over the range of samples (Figure 3).

Several sources of error are possible when estimating the size of a fish from its otoliths, among which are normal variability in the ratio of fish length to otolith length and differences in lengths of left and right otoliths of the same fish. The calculated regression coefficients show that such variability is quite small. Deviation between actual measured and calculated fish lengths was usually <5%. Since food habits studies deal with

TABLE 2.—Sources of Alaskan marine gadids measured to determine otolith length-fish size relationships. T = *Theragra chalcogramma*; E = *Eleginus gracilis*; B = *Boreogadus saida*.

Vessel and cruise no.	Date	Area	Depth range (m)	Trawls (no.)	Species
NOAA[1] Ship *Surveyor* (RP-4-SU-76AI&II)	Mar.-Apr. 1976	Bering	79-173	39	T
NOAA Ship *Discoverer* (RP-4-DI-76BIII)	Aug. 1976	Bering/Chukchi	18-55	18	B, E
USCGC[2] *Glacier* (AWS76)	Aug. 1976	Beaufort	40-123	2	B
NOAA Ship *Miller Freeman* (RD-4-MF-76BII)	Oct. 1976	Bering	15-55	75	B, E
NOAA Ship *Surveyor* (RD-4-SU-77AII, III)	Mar.-Apr. 1977	Bering	28-150	45	T, E
NOAA Ship *Discoverer* (RD-4-DI-77AVI)	May-June 1977	Bering	30-150	36	B, T
NOAA Ship *Surveyor* (RD-4-SU-77BII)	June-July 1977	Bering/Chukchi	13-57	17	B, E
USCGC *Glacier* (AWS77III)	Aug.-Sept. 1977	Chukchi/Beaufort	31-400	33	B
ADF&G[3] skiff (Shishmaref 78)	Mar. 1978	Chukchi	5-10	5	E
NOAA Ship *Surveyor* (RP-4-SU-78AV, VI)	May-June 1978	Bering	17-210	78	T, E

[1]National Oceanic and Atmospheric Administration.
[2]United States Coast Guard Cutter.
[3]Alaska Department of Fish and Game.

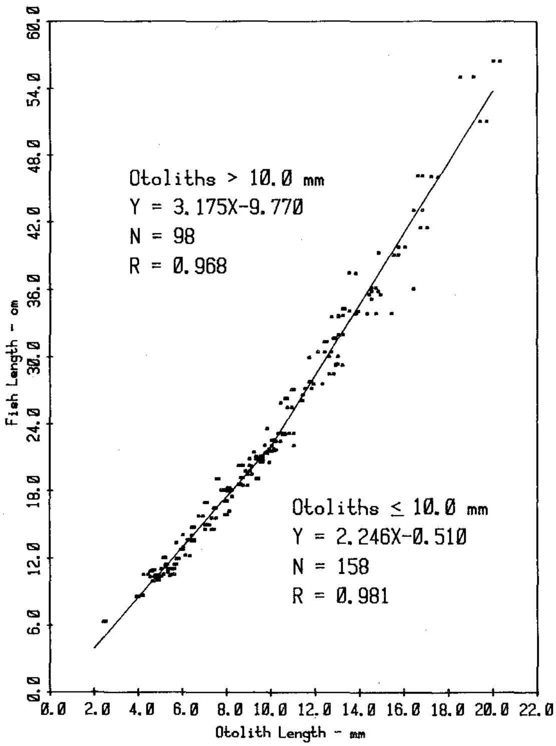

FIGURE 1.—Scatter diagram and regression lines and equations of otolith length against fish fork length for *Theragra chalcogramma*.

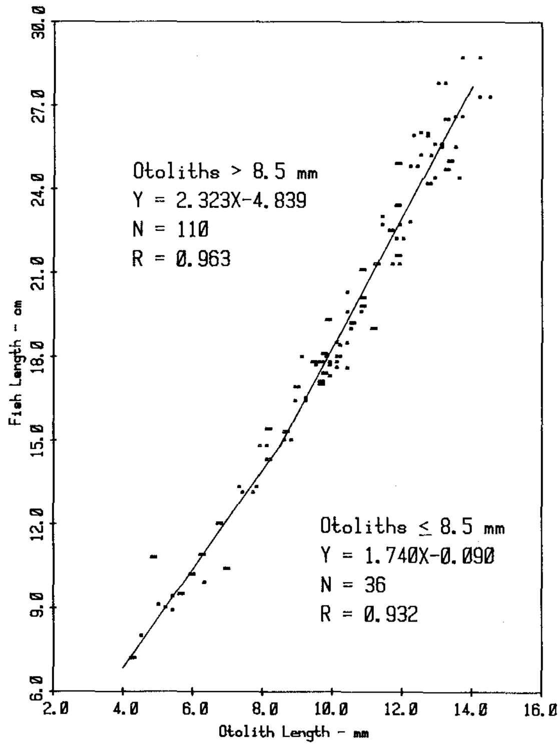

FIGURE 2.—Scatter diagram and regression lines and equations of otolith length against fish fork length for *Eleginus gracilis*.

mixed collections of otoliths, the cumulative importance of these differences should be minimal.

The relationships between fish lengths and weights of the three species were best fit by exponential equations of the form: weight = a (length)^b (Table 3). These relationships may vary somewhat with time of year, geographic location, sex, reproductive status, or fullness of stomach. Variation is probably most pronounced in sexually mature individuals with mature reproductive products, a condition which persists for only a few months of the year. Since small (juvenile) fishes are eaten by most marine mammals (Frost and Lowry 1980), birds (Hunt et al. in press), and other fishes (Frost and Lowry unpubl. data), this is probably a small source of error. Significant differences in weight-at-length by sex and geographic area were found for Arctic and saffron cods by Wolotira et al.[2] but they justified use of a single regression equation since the differences were small (3-7%). Similar differences have been noted for walleye pollock (Bakkala and Smith[3]).

Otoliths are valuable indicators of the diet of piscivorous marine consumers. Published keys such as Morrow (1979) allow determination of the species and numbers of fishes represented by otoliths in stomachs, intestines, or scats. By using the relationships between otolith size and body

TABLE 3.—Length-weight relationships observed for walleye pollock, saffron cod, and Arctic cod in the Bering, Chukchi, and Beaufort Seas (weight = a(length)^b).

Species	Number sampled	Range in fork length (cm)	a	b	Regression coefficient (r)
Walleye pollock	109	6-57	0.0077	2.906	0.998
Saffron cod	104	6-29	.0050	3.095	.991
Arctic cod	118	7-21	.0018	3.500	.987

[2]Wolotira, R. J., Jr. 1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea and adjacent waters in the baseline year 1976. Processed rep., 292 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard E., Seattle, WA 98112.

[3]Bakkala, R. G., and G. B. Smith. 1978. Demersal fish resources of the eastern Bering Sea: Spring 1976. Processed rep., 233 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard E., Seattle, WA 98112.

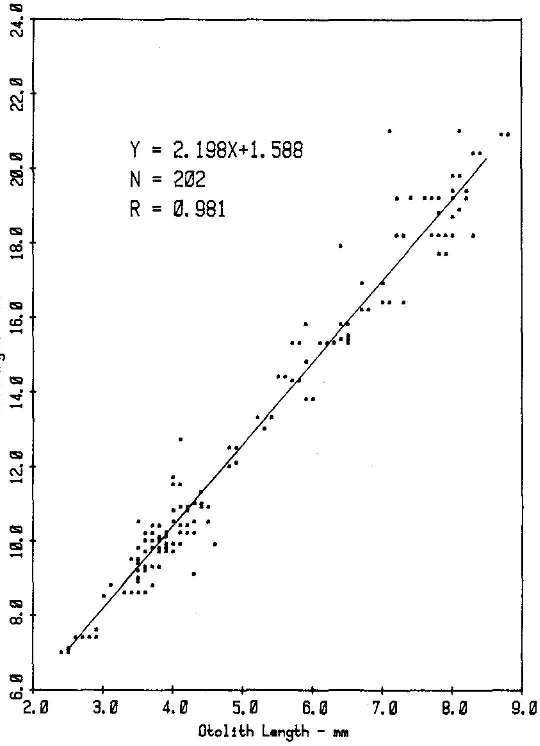

FIGURE 3.—Scatter diagram and regression lines and equations of otolith length against fish fork length for *Boreogadus saida*.

size it is possible to obtain additional information such as sizes and quantities of fishes eaten by consumers (Frost and Lowry 1980).

Acknowledgments

Many people assisted us in the collection of samples, especially Larry M. Shults who spent many long hours sorting through trawls and measuring fish with us, and the officers and crew of the NOAA Ship *Surveyor* who gave unstintingly of their time and energy to make our project a success. Lawrence R. Miller provided invaluable assistance in the computer analysis of our data. We thank J. E. Morrow and anonymous reviewers for their careful review of the manuscript. We are especially indebted to John Fitch for his many helpful suggestions and the moral support he lent throughout preparation of this manuscript. Financial support was provided by the U.S. Bureau of Land Management Outer Continental Shelf Environmental Assessment Program and Federal Aid in Wildlife Restoration Project W-17-9.

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KATHRYN J. FROST
LLOYD F. LOWRY

Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701

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