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ABSTRACT

Otoliths commonly are used to determine the taxon, age, and size of fishes. This information is useful for population management, predator-prey studies, and archaeological research. The relationship between the length of a fish and the length of its otoliths remains unknown for many species of marine fishes in the Pacific Ocean. Therefore, the relationships between fish length and fish weight, and between otolith length and fish length, were developed for 63 species of fishes caught in the eastern North Pacific Ocean. We also summarized similar relationships for 46 eastern North Pacific fish species reported in the literature. The relationship between fish length and otolith length was linear, and most of the variability was explained by a simple least-squares regression ($r^2 > 0.700$ for 45 of 63 species). The relationship between otolith length and fish length was not significantly different between left and right otoliths for all but one fish species. Images of otoliths from 77 taxa are included to assist in the identification of species.

Introduction

All bony fishes (Osteichthyes) have three pairs of otoliths (earbones or earstones): the sagittae, asteriscus, and lapillus. These otoliths are composed of calcium carbonate in the form of aragonite, in a protein matrix. They are contained within membranous labyrinths in paired otic capsules on either side of the skull. The sagittae are the largest pair of otoliths in most bony fishes; however, in minnows (Cypriniformes) and catfish (Siluriformes) the asterici are the largest (Hecht, 1977). Fisheries biologists have used sagittae to determine age and growth of fishes because of the large size and distinct growth rings of sagittae (Chilton and Beamish, 1982; Boehlert, 1985; Summerfelt and Hall, 1987).

Because otoliths are dense they can withstand some degree of dissolution, and often species can be recognized by the distinctive morphology of the sagittae (Morrow, 1979; Smale et al., 1995). Paleontologists have identified otoliths in middens (Fitch, 1969), oceanographers have determined species of fishes from otoliths in sediments (Fitch, 1964, 1968), and prey have been identified using otoliths collected from stomachs of piscivorous fishes (Trippel and Beamish, 1987), marine birds (Ainley et al., 1981), and marine mammals (Fitch and Brownell, 1968; Treacy and Crawford, 1981). Fishes eaten by pinnipeds also were identified using otoliths found in feces (Bailey and Ainley, 1982; Brown and Mate, 1983; Antonelis et al., 1984; Harvey, 1987).

Trout (1954) and Templemann and Squires (1956) were among the first to demonstrate a significant positive relationship between otolith size and fish size of Barents Sea cod (*Boreogadus saida*) and haddock (*Melanogrammus aeglefinus*). Otolith length also has been correlated with fish weight (Casteel, 1976). Since these early studies, relationships between otolith length and fish length have been determined for some species, including North Pacific gadids (Frost and Lowry, 1981), rockfishes (*Sebastes* spp.; Wyllie Echeverria, 1987), and several fishes off Baja California, Mexico (Gamboa, 1991).

For most species, the relationship between otolith length and fish length can be described by a simple linear regression. For North Pacific gadids, this relation-

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ship has been best described by two linear regressions with an inflection point (Frost and Lowry, 1981). Left and right sagittae also may differ in size within a rockfish species (Wyllie Echeverria, 1987), and sometimes otolith size is different among stocks of fishes, such as Atlantic herring (*Clupea harengus*; Messieh, 1972).

The objective of this study was to compile information regarding the relationship between otolith length and fish length for fish species of the eastern North Pacific Ocean using original collections and published and unpublished literature. These data may be used by researchers studying archaeology and food habits of piscivores to determine the size of fishes from the length of recovered otoliths. We also wanted to provide images of most fish otoliths, for which we had regressions, to be used as an aid for identifying species of fish.

Methods

Fishes were collected throughout the eastern North Pacific Ocean (e.g. Bering Sea, Gulf of Alaska, and off Washington, Oregon, and California) using bottom and midwater trawls, beach seines, gill nets, and hook-and-line gear. Fish were weighed to the nearest 0.1 g on a Mettler balance (<600 g) and spring or pan scale (>600 g). Standard length (SL; most anterior point to the base of hypural plate at caudal flexion) or fork length (FL; most anterior point to the base of the fork in the caudal fin) was measured to the nearest millimeter.

Sagittae were removed, cleaned, and stored dry in vials. Lengths of sagittae were determined using hand-held vernier calipers under a dissecting microscope. Sagittal otolith length was recorded as the greatest distance measured from the anterior rostrum to the posterior edge, parallel to the sulcus.

The relationship between otolith length and fish length (SL or FL) was determined using a least-squares linear regression. The appropriateness of the linear model was determined by plotting the residuals against the independent variable. Differences between regression coefficients for the relationship of fish length and the lengths of left and right otoliths were tested using t tests. When the equations for left and right otoliths did not differ statistically, one right or left otolith was selected randomly from each individual and a single linear regression reported for each fish species. The significance of the linear regression was tested using an analysis of variance (ANOVA). Relationships between otolith length and fish length for additional species were obtained from published and unpublished sources. Relationships between fish length and fish weight were determined using a least-squares regression of the log of fish weight and length (Ricker, 1975). Although transformation back to arithmetic units may result in underestimating weight, these errors are usually small (Saila et al., 1988).

Results

Forty-six relationships between fish and otolith size previously reported in the literature involved various measures of fish length—fork length, total length (defined as the distance from the most anterior point to the most posterior point), and standard length measured in millimeters or centimeters—and otolith length (Table 1). Many of the published regressions of fish length to otolith length were developed for species common in food habit studies of marine mammals (Frost and Lowry, 1981; Brown and Mate, 1983) or species that were commercially important (Spratt, 1975; Boehlert and Yoklavich, 1984; Wyllie Echeverria, 1987).

Sixty-three species of fishes were collected in connection with the current study (Table 2). Most relationships between weight and length were described by a traditional allometric equation, where weight of a fish is approximately equal to length to the third power (Table 2). Linearized forms of this power relationship explained >90% of the variability in 43 of 60 cases. For three species, no weight data were collected. For 17 additional species, the sample size was less than 20; therefore, these weight/length relationships should be used with caution.

Generally the relationship between fish length and otolith length was linear, and most of the variability was explained by the regression ($r^2>0.700$ in 45 of 63 cases; Table 2). All relationships except one were significant ($P<0.05$). There was no significant relationship between otolith length and fish length for *Trachurus symmetricus* (Table 2). Regression coefficients of otolith length to fish length were not significantly different for left and right otoliths, except for the wattled eelpout (*Lycodes palearis*; $P<0.05$), however, the analysis was probably influenced by the small sample size ($n=12$). Size of fish should not be predicted from otolith size or fish weight for measurements outside the range used for the regressions.

To assist in the identification of recovered otoliths, we provide images of fish otoliths (Fig. 1) for most species sampled. These otoliths are listed according to taxonomic relationships (Robins et al., 1991). We chose otoliths that were representative of the species, and presented multiple images of otoliths from species where the otolith morphology changed with size.

Discussion

Otoliths have been used to identify fish species eaten by marine predators (Fitch and Brownell, 1968; Pitcher, 1980;

Table 1

Published relationships of fish otolith length (or mass) and fish length (or mass) for fishes in the eastern North Pacific. NA indicates data not available, and the codes for the variables (x and y) are defined at the bottom of the table.

Species	Regression	Variables	r^2	n	Location	Reference
Boreogadus saida (Arctic cod)	$y = 2.20x + 1.59$	b	0.98	202	Beaufort & Chukchi Seas	Frost and Lowry (1981)
Citharichthys sordidus (Pacific sanddab)	$y = 0.02x + 1.02$	a	0.93	46	Oregon	Brown and Mate (1983)
Eleginus gracilis (saffron cod)	$y = 2.32x - 4.84$	b, c	0.96	110	Bering & Chukchi Seas	Frost and Lowry (1981)
	$y = 1.74x - 0.09$	b, d	0.93	36		
Engraulis mordax (northern anchovy)	$y = 33.22x - 8.49$	e	0.88	121	California	Spratt (1975)
Errex zachirus (rex sole)	$y = 0.02x + 1.02$	a	0.98	78	Oregon	Brown & Mate (1983)
Hippoglossus stenolepis (Pacific halibut)	$\ln(y) = 1.31 \ln x - 1.32$	b	NA	2,503	North Pacific	Southward (1962)
	$\ln(y) = 1.97 \ln x + 6.00$		0.90	128	North Pacific	Southward and Chapman (1965)
Leptocottus armatus (staghorn sculpin)	$y = 0.03x + 1.31$	a	0.98	14	Oregon	Brown and Mate (1983)
Lyopsetta exilis (slender sole)	$y = 0.02x + 0.30$	a	0.98	47	Oregon	Brown and Mate (1983)
Microstomus pacificus (dover sole)	$y = 0.02x + 0.62$	a	0.97	45	Oregon	Brown and Mate (1983)
Oncorhynchus keta (chum salmon)	$\log_{10}y = 1.23 + 3.21 \log_{10}x$	f	0.99	43	North Pacific	Casteel (1974)
Oncorhynchus kisutch (coho salmon)	$\log_{10}y = 0.89 + 5.93 \log_{10}x$	f	0.99	19	North Pacific	Casteel (1974)
Oncorhynchus mykiss (rainbow trout)	$y = 0.006x + 2.16$	a	0.97	121	British Columbia, Washington, Oregon	McKern et al. (1974)
Oncorhynchus nerka (sockeye salmon)	$\log_{10}y = 0.29 + 4.13 \log_{10}x$	f	0.95	86	North Pacific	Casteel (1974)
Oncorhynchus tshawytscha (chinook salmon)	$\log_{10}y = 0.59 + 4.15 \log_{10}x$	f	0.99	53	North Pacific	Casteel (1974)
Pleuronectes vetulus (English sole)	$y = 0.03x + 0.53$	a	0.99	81	Oregon	Brown and Mate (1983)
Sebastes auriculatus (brown rockfish)	$y = 33.16x - 53.03$	g	0.94	78	California	Wyllie Echeverria (1987)
Sebastes aurora (aurora rockfish)	$y = 19.91x + 15.12$	g	0.61	71	California	Wyllie Echeverria (1987)
Sebastes carnatus (gopher rockfish)	$y = 30.57x - 39.37$	g	0.89	203	California	Wyllie Echeverria (1987)
Sebastes caurinus (copper rockfish)	$y = 30.23x + 5.10$	g	0.82	132	California	Wyllie Echeverria (1987)
Sebastes chlorostictus (greenspotted rockfish)	$y = 24.11x - 18.54$	g	0.95	174	California	Wyllie Echeverria (1987)
Sebastes chrysomelas (black-and-yellow rockfish)	$y = 28.61x - 21.78$	g	0.84	166	California	Wyllie Echeverria (1987)
Sebastes constellatus (starry rockfish)	$y = 25.27x - 37.48$	g	0.96	99	California	Wyllie Echeverria (1987)
Sebastes crameri (darkblotched rockfish)	$y = 28.10x - 27.10$	g	0.94	89	California	Wyllie Echeverria (1987)
Sebastes diploproa (splitnose rockfish)	$y = 22.64x - 12.85$	g	0.96	78	California	Wyllie Echeverria (1987)
Sebastes elongatus (greenstriped rockfish)	$y = 24.02x - 13.56$	g	0.95	98	California	Wyllie Echeverria (1987)
Sebastes entomelas (widow rockfish)	$y = 33.11x - 6.89$	g	0.81	106	California	Wyllie Echeverria (1987)
Sebastes flavidus (yellowtail rockfish)	$y = 26.51x - 10.95$	g	0.88	184	California	Wyllie Echeverria (1987)
Sebastes goodei (chilipepper)	$y = 29.13x - 58.00$	g	0.96	78	California	Wyllie Echeverria (1987)
Sebastes hopkinsi (squarespot rockfish)	$y = 28.87x - 30.55$	g	0.92	59	California	Wyllie Echeverria (1987)
Sebastes jordani (shortbelly rockfish)	$y = 22.10x - 2.31$	g	0.97	183	California	Wyllie Echeverria (1987)

Continued

Table 1 (continued)

Species	Regression	Variables	r^2	n	Location	Reference
Sebastes levis (cowcod)	$y = 47.46x - 170.11$	g	0.95	29	California	Wyllie Echeverria (1987)
Sebastes maliger (quillback rockfish)	$y = 29.97x - 53.11$	g	0.86	34	California	Wyllie Echeverria (1987)
Sebastes melanops (black rockfish)	$y = 30.56x - 48.22$	g	0.86	209	California	Wyllie Echeverria (1987)
Sebastes melanostomus (blackgill rockfish)	$y = 30.56x - 47.07$	g	0.86	80	California	Wyllie Echeverria (1987)
Sebastes miniatus (vermilion rockfish)	$y = 29.36x - 56.74$	g	0.93	99	California	Wyllie Echeverria (1987)
Sebastes mystinus (blue rockfish)	$y = 29.77x - 18.18$	g	0.83	204	California	Wyllie Echeverria (1987)
Sebastes nebulosus (China rockfish)	$y = 25.18x + 32.97$	g	0.79	48	California	Wyllie Echeverria (1987)
Sebastes ovalis (speckled rockfish)	$y = 33.56x - 53.47$	g	0.91	84	California	Wyllie Echeverria (1987)
Sebastes paucispinis (bocaccio)	$y = 41.09x - 77.09$	g	0.82	86	California	Wyllie Echeverria (1987)
Sebastes pinniger (canary rockfish)	$y = 29.41x - 85.11$	g	0.92	173	California	Wyllie Echeverria (1987)
Sebastes rosaceus (rosy rockfish)	$y = 22.53x - 83.48$	g	0.81	147	California	Wyllie Echeverria (1987)
Sebastes ruberrimus (yelloweye rockfish)	$y = 31.33x - 76.23$	g	0.92	102	California	Wyllie Echeverria (1987)
Sebastes saxicola (stripetail rockfish)	$y = 23.40x - 32.77$	g	0.95	102	California	Wyllie Echeverria (1987)
Sebastes semicinctus (halfbanded rockfish)	$y = 25.27x - 19.18$	g	0.85	31	California	Wyllie Echeverria (1987)
Sebastes serranoides (olive rockfish)	$y = 29.35x - 51.01$	g	0.93	130	California	Wyllie Echeverria (1987)
Theragra chalcogramma (walleye pollock)	$y = 3.18x - 9.77$	b, h	0.97	98	Bering Sea	Frost and Lowry (1981)
	$y = 2.25x - 0.51$	b, i	0.98	158		

[a] x = fish standard length (mm), y = otolith length (mm)
[b] x = otolith length (mm), fish fork length (cm)
[c] otolith length > 8.5 mm
[d] otolith length < 8.5 mm
[e] x = otolith length (mm), fish standard length (mm)
[f] x = otolith length (mm), x = fish weight (g)
[g] x = otolith length (mm), x = fish total length (mm)
[h] otolith length > 10.0 mm
[i] otolith length < 10.0 mm

Table 2

Relationships of fish weight (WT) in grams to fish standard length (SL) in centimeters, and standard length to length of otolith (OL) in millimeters. For each equation, the number of fish or otoliths measured (*N*), coefficient of determination (r^2), standard error of the regression coefficient (SE_β), and range of fish lengths is given. Species and common names from Robins et al. (1991).

		Fish weight/fish length			Fish length/otolith length			
Species (common name)	Location[1]	Equation	*N*	r^2	Equation	*N*	r^2	Range
Allosmerus elongatus (whitebait smelt)	OR	$WT = 0.0063\ SL^{3.233}$	25	0.893	SL = 2.11 (OL) + 3.02	23	0.838	7.9–9.7
Alosa sapidissima (American shad)	OR	$WT = 0.0135\ SL^{3.046}$	7	0.997	SL = 11.46 (OL) – 11.08 $SE_\beta = 0.680$	14	0.960	8.4–37.1
Ammodytes hexapterus (Pacific sand lance)	CA AK	$WT = 0.0063\ SL^{2.790}$	10	0.913	SL = 4.06 (OL) + 2.01 $SE_\beta = 1.643$	10	0.433	9.3–13.6
Anoplopoma fimbria (sablefish)	OR	$WT = 0.0163\ SL^{2.902}$	74	0.993	SL = 5.28 (OL) + 1.62 $SE_\beta = 0.120$	94	0.955	9.3–46.7
Atheresthes stomias (arrowtooth flounder)	OR	$WT = 0.0093\ FL^{2.999}$	101	0.961	FL = 4.75 (OL) – 2.96	84	0.925	31.1–37.5
Atherinops affinis (topsmelt)	CA	$WT = 0.1698\ SL^{1.733}$	14	0.429	SL = 3.72 (OL) + 0.55 $SE_\beta = 0.325$	18	0.891	4.1–14.1
Atherinopsis californiensis (jacksmelt)	CA	$WT = 0.0049\ SL^{3.228}$	12	0.968	SL = 4.85 (OL) – 2.46 $SE_\beta = 0.279$	18	0.950	13.0–32.6
Bathymaster signatus (searcher)	WA	$WT = 0.0038\ SL^{3.256}$	44	0.991	SL = 3.48 (OL) + 1.90	43	0.883	11.8–31.5
Chilara taylori (spotted cusk-eel)	CA	$WT = 0.0004\ SL^{3.761}$	22	0.964	SL = 2.51 (OL) + 2.15 $SE_\beta = 0.294$	29	0.730	11.4–25.2
Chitonotus pugetensis (roughback sculpin)	WA	$WT = 0.0217\ SL^{2.871}$	11	0.960	SL = 3.37 (OL) – 4.52 $SE_\beta = 0.460$	11	0.857	5.5–11.8
Citharichthys sordidus (Pacific sanddab)	WA, OR	$WT = 0.0352\ SL^{2.710}$	60	0.851	SL = 2.87 (OL) + 3.29 $SE_\beta = 0.229$	61	0.727	3.3–25.5
Clupea pallasi (Pacific herring)	WA, OR	$WT = 0.0044\ SL^{3.398}$	83	0.976	SL = 5.24 (OL) – 1.85 $SE_\beta = 0.166$	82	0.934	5.1–22.7
Coryphaenoides acrolepis (Pacific rattail)	OR	$WT = 0.0016\ SL^{3.209}$	10	0.921	SL = 3.44 (OL) – 3.23 $SE_\beta = 0.368$	10	0.926	19.0–36.0
Cymatogaster aggregata (shiner perch)	OR, CA	$WT = 0.0100\ SL^{3.515}$	85	0.979	SL = 1.74 (OL) – 0.52 $SE_\beta = 0.053$	90	0.925	4.8–12.2
Dasycottus setiger (spinyhead sculpin)	GA	No data available			FL = 3.11 (OL) – 7.03 $SE_\beta = 0.368$	49	0.655	8.0–33.0
Eleginus gracilis (saffron cod)	GA	$WT = 0.0039\ SL^{3.292}$	13	0.990	SL = 1.89 (OL) – 2.76 $SE_\beta = 0.058$	46	0.960	9.2–20.9
Embiotoca jacksoni (black perch)	CA	$WT = 0.0282\ SL^{3.148}$	19	0.992	SL = 2.45 (OL) – 2.61 $SE_\beta = 0.082$	52	0.947	5.2–18.4
Embiotoca lateralis (striped seaperch)	OR, CA	$WT = 0.0329\ SL^{3.043}$	25	0.998	SL = 2.90 (OL) – 5.68 $SE_\beta = 0.061$	25	0.990	6.6–26.4
Engraulis mordax (northern anchovy)	CA	$WT = 0.0485\ SL^{2.413}$	34	0.807	SL = 2.28 (OL) + 0.85 $SE_\beta = 0.206$	56	0.694	3.6–14.4
Eopsetta exilis (slender sole)	GA	$WT = 0.0058\ SL^{3.293}$	50	0.974	SL = 3.37 (OL) + 1.08 $SE_\beta = 0.265$	50	0.771	8.0–20.5

Continued

Table 2 (continued)

Species (common name)	Location[1]	Fish weight/fish length: Equation	N	r^2	Fish length/otolith length: Equation	N	r^2	Range
Eopsetta jordani (petrale sole)	OR, CA	$WT = 0.0086\ SL^{3.231}$	17	0.986	SL = 4.85 (OL) – 4.81 $SE_{\beta} = 0.468$	20	0.857	13.7–37.0
Errex zachirus (rex sole)	WA, OR	$WT = 0.0238\ SL^{2.692}$	67	0.932	SL = 4.80 (OL) – 2.50 $SE_{\beta} = 0.226$	70	0.869	12.0–29.7
Gadus macrocephalus (Pacific cod)	BS	No data available			FL = 4.51 (OL) – 22.97	110	0.883	10.0–106.0
Genyonemus lineatus (white croaker)	CA	$WT = 0.0550\ SL^{2.700}$	40	0.767	SL = 1.52 (OL) + 4.66 $SE_{\beta} = 0.209$	48	0.534	9.1–28.0
Gymnocanthus galeatus (armorhead sculpin)	BS	$WT = 0.0100\ SL^{3.196}$	29	0.939	SL = 1.75 (OL) + 0.82 $SE_{\beta} = 0.360$	28	0.476	7.3–15.0
Hippoglossoides elassodon (flathead sole)	WA	$WT = 0.0078\ FL^{3.041}$	99	0.984	FL = 4.63 (OL) – 0.71	40	0.947	17.2–30.5
Hyperprosopon argenteum (walleye surfperch)	OR, CA	$WT = 0.0116\ SL^{3.361}$	23	0.996	SL = 2.57 (OL) – 2.83 $SE_{\beta} = 0.063$	24	0.987	5.6–20.7
Hypomesus pretiosus (surf smelt)	OR	$WT = 0.0044\ SL^{3.345}$	42	0.986	SL = 3.61 (OL) – 0.63 $SE_{\beta} = 0.204$	25	0.932	6.9–15.4
Hypsopsetta guttulata (diamond turbot)	CA	$WT = 0.0853\ SL^{2.664}$	14	0.967	SL = 4.89 (OL) – 0.29 $SE_{\beta} = 0.543$	18	0.835	7.1–26.9
Leptocottus armatus (Pacific staghorn sculpin)	WA,OR,CA	$WT = 0.0111\ SL^{3.229}$	51	0.990	SL = 2.58 (OL) – 2.26 $SE_{\beta} = 0.092$	62	0.928	3.7–22.5
Lycodes brevipes (shortfin eelpout)	BS	$WT = 0.0195\ FL^{2.522}$	56	0.826	FL = 3.47 (OL) + 4.83 $SE_{\beta} = 0.430$	62	0.520	18.5–27.6
Lycodes cortezianus (bigfin eelpout)	WA,CA	$WT = 0.0018\ SL^{3.245}$	40	0.993	SL = 10.96 (OL) – 21.82	41	0.742	11.5–44.7
Lycodes palearis (wattled eelpout)	BS	$WT = 0.0007\ FL^{3.483}$	25	0.913	FL = 5.22 (OL) + 12.42 $SE_{\beta} = 1.773$	24	0.283	32.0–47.0
Lycodopsis pacifica (blackbelly eelpout)	GA	$WT = 0.0018\ SL^{3.302}$	22	0.954	SL = 3.82 (OL) + 4.89 $SE_{\beta} = 0.719$	20	0.610	14.4–23.3
Mallotus villosus (capelin)	BS	$WT = 0.0054\ SL^{3.160}$	39	0.717	SL = 3.45 (OL) + 3.62 $SE_{\beta} = 0.417$	39	0.649	10.0–13.7
Merluccius productus (Pacific hake)	OR	$WT = 0.0081\ SL^{2.966}$	75	0.933	SL = 2.04 (OL) + 0.96 $SE_{\beta} = 0.078$	86	0.891	26.3–54.4
Microgadus proximus (Pacific tomcod)	WA,OR	$WT = 0.0064\ SL^{3.191}$	80	0.988	SL = 1.77 (OL) – 3.51 $SE_{\beta} = 0.048$	101	0.932	6.1–28.3
Microstomus pacificus (Dover sole)	OR	$WT = 0.0094\ SL^{3.092}$	101	0.854	SL = 3.72 (OL) + 6.97 $SE_{\beta} = 0.301$	117	0.587	7.6–37.8
Oncorhynchus kisutch (coho salmon)	OR	$WT = 0.0103\ SL^{3.092}$	43	0.989	SL = 16.31 (OL) – 40.74 $SE_{\beta} = 2.138$	46	0.569	12.5–58.4
Oncorhynchus mykiss (rainbow trout)	OR	$WT = 0.0275\ SL^{2.895}$	18	0.905	SL = 16.28 (OL) – 38.14 $SE_{\beta} = 1.381$	39	0.790	12.0–26.1
Ophiodon elongatus (lingcod)	OR,CA	$WT = 0.0023\ SL^{3.567}$	10	0.620	SL = 8.23 (OL) – 8.20 $SE_{\beta} = 0.315$	35	0.722	5.3–71.9
Osmerus mordax (rainbow smelt)	BS	$WT = 0.0038\ SL^{3.278}$	32	0.819	SL = 2.69 (OL) + 0.32 $SE_{\beta} = 0.292$	29	0.759	13.0–17.9

Continued

Table 2 (continued)

		Fish weight/fish length			Fish length/otolith length			
Species (common name)	Location[1]	Equation	N	r^2	Equation	N	r^2	Range
Phanerodon furcatus (white seaperch)	OR,CA	$WT = 0.0213\ SL^{3.086}$	17	0.997	$SL = 2.33\ (OL) - 2.15$ $SE_\beta = 0.109$	46	0.912	4.5–23.5
Platichthys stellatus (starry flounder)	OR,CA	$WT = 0.0107\ SL^{3.268}$	25	0.985	$SL = 3.35\ (OL) + 0.23$ $SE_\beta = 0.303$	30	0.814	8.2–37.3
Pleurogrammus monopterygius (Atka mackerel)	BS	$WT = 0.0034\ FL^{3.401}$	16	0.987	$FL = 8.40\ (OL) - 4.99$	13	0.864	19.0–35.0
Pleuronectes asper (yellowfin sole)	BS	$WT = 0.0024\ SL^{3.605}$	7	0.859	$SL = 2.17\ (OL) + 10.65$	26	0.638	22.7–30.7
Pleuronectes bilineatus (rock sole)	BS	$WT = 0.0112\ FL^{2.997}$	83	0.931	$FL = 6.16\ (OL) - 6.97$	29	0.841	7.3–32.0
Pleuronectes vetulus (English sole)	WA,OR,CA	$WT = 0.0163\ SL^{2.939}$	98	0.995	$SL = 3.82\ (OL) - 2.76$ $SE_\beta = 0.059$	151	0.965	3.5–36.1
Podothecus acipenserinus (sturgeon poacher)	BS,WA, OR	$WT = 0.0030\ SL^{3.233}$	93	0.956	$SL = 6.58\ (OL) - 6.21$ $SE_\beta = 0.303$	92	0.840	7.3–25.7
Porichthys notatus (plainfin midshipman)	WA,OR, CA	$WT = 0.0207\ SL^{2.916}$	78	0.967	$SL = 2.80\ (OL) - 2.59$ $SE_\beta = 0.090$	80	0.926	4.0–26.6
Psettichthys melanostictus (sand sole)	WA,OR, CA	$WT = 0.0052\ SL^{3.441}$	25	0.983	$SL = 5.06\ (OL) - 3.18$ $SE_\beta = 0.256$	26	0.942	8.1–31.0
Rhacochilus vacca (pile perch)	WA,OR	$WT = 0.0182\ SL^{3.218}$	46	0.997	$SL = 3.35\ (OL) - 8.19$ $SE_\beta = 0.098$	45	0.965	6.2–33.5
Sebastes melanops (black rockfish)	OR	$WT = 0.1225\ SL^{2.499}$	21	0.585	$SL = 2.23\ (OL) - 1.48$ $SE_\beta = 0.181$	53	0.749	12.2–42.0
Sebastes paucispinis (bocaccio)	OR	No data available			$SL = 2.41\ (OL) + 0.14$ $SE_\beta = 0.398$	13	0.769	8.4–41.8
Sebastolobus alascanus (shortspine thornyhead)	OR	$WT = 0.0102\ SL^{3.239}$	69	0.988	$SL = 2.31\ (OL) - 3.71$ $SE_\beta = 0.150$	51	0.828	15.1–49.2
Sebastolobus altivelis (longspine thornyhead)	OR	$WT = 0.0155\ SL^{3.113}$	13	0.997	$SL = 4.94\ (OL) - 27.50$ $SE_\beta = 0.652$	13	0.839	15.8–55.5
Spirinchus thaleichthys (longfin smelt)	OR	$WT = 0.0288\ SL^{2.531}$	50	0.854	$SL = 2.64\ (OL) - 0.20$ $SE_\beta = 0.142$	50	0.878	7.3–11.6
Symphurus atricauda (California tonguefish)	CA	$WT = 0.0074\ SL^{3.136}$	32	0.789	$SL = 3.56\ (OL) + 4.64$ $SE_\beta = 0.563$	48	0.464	6.5–15.2
Thaleichthys pacificus (eulachon)	OR	$WT = 0.0077\ SL^{3.075}$	129	0.884	$SL = 4.71\ (OL) - 2.70$ $SE_\beta = 0.181$	102	0.871	10.5–19.8
Theragra chalcogramma (walleye pollock)	WA	$WT = 0.0043\ SL^{3.255}$	46	0.985	$SL = 2.24\ (OL) - 2.35$ $SE_\beta = 0.081$	44	0.948	12.6–43.2
Trachurus symmetricus (jack mackerel)	OR,CA	$WT = 0.0635\ SL^{2.556}$	18	0.761	Not significant	14	0.141	25.5–33.3
Trichodon trichodon (Pacific sandfish)	BS	$WT = 0.0170\ FL^{2.953}$	19	0.971	$FL = 6.06\ (OL) - 4.57$	17	0.684	15.0–25.0
Zalembius rosaceus (pink seaperch)	CA	$WT = 0.0199\ SL^{3.102}$	48	0.841	$SL = 1.88\ (OL) - 0.07$ $SE_\beta = 0.079$	56	0.912	7.0–12.8

[1] Location of capture: BS = Bering Sea, CA = California, GA = Gulf of Alaska, OR = Oregon, WA = Washington.

Brown and Mate, 1983; Harvey, 1987). Specific guides or keys to fish otoliths also have been published (Morrow, 1979; Harkonen, 1986; Hecht, 1987; Smale et al., 1995).

Generally, standard length of fishes is linearly related to otolith length. Predicting size of fishes (length and weight) can be accomplished with fair reliability on the basis of otolith length. This relationship, however, is not always reliable. Otolith length typically is linearly related to length of the fish until the fish reaches maximum size; thereafter, the otolith increases only in thickness (Blacker, 1974; Williams and Bedford, 1974). Otolith lengths of larval and juvenile fishes may increase in a curvilinear fashion relative to fish length for some species, such as sockeye salmon (*Oncorhynchus nerka*; West and Larkin, 1987) and walleye pollock (*Theragra chalcogramma*; Nishimura and Yamada, 1988). The relationship between otolith length and fish length may be dependent on the growth rate of the fish, as was reported for striped bass (*Morone saxatilis*; Secor and Dean, 1989). Additionally, the relationship between otolith length and fish length may be described by multiple linear lines with inflection points (e.g. gadids; Frost and Lowry, 1981). Multiple linear relationships may result from different growth stanzas (Laidig et al., 1991). These results indicate that size of fish should only be estimated over the size distribution sampled, and that all length intervals should be sampled properly with the appropriate statistical model.

Estimating size of consumed fishes from measurements of otoliths recovered in stomachs or feces may be biased because of partial or complete digestion of otoliths (Jobling and Breiby, 1986; Jobling, 1987). For instance, size of fish eaten by the harbor seal (*Phoca vitulina*) may be underestimated by 16–44% (Harvey, 1989). Similar results have been reported for many pinnipeds (Hawes, 1983; da Silva and Neilson, 1985; Murie and Lavigne, 1986). Although a rough estimate of these errors may be obtained from controlled experiments, the amount of digestion may be species-specific, requiring numerous tests to document all forms of bias. There also may be differences between the sexes in the relationship between fish size and otolith size, something we did not test. Researchers using otoliths to determine number and size of fish eaten, therefore, should realize the limitations of this technique.

Fish size-otolith size relationships will be useful for researchers examining food habits of piscivores and size of fish in archaeological samples. Many more species and sizes of fish should be sampled to cover the full range of fishes involved in these studies.

Acknowledgments

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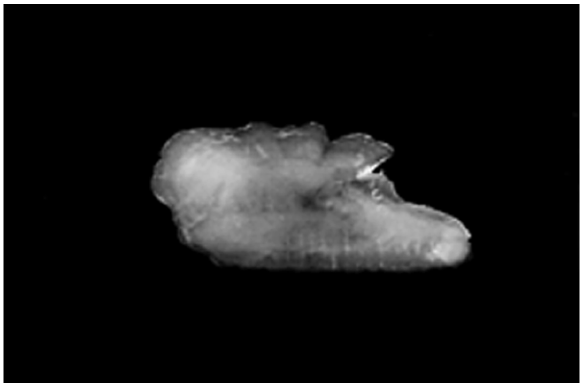
Figure 1

Otolith images of 76 species of fishes from the eastern North Pacific, listed in taxonomic order (Robins et al., 1991). For species with extreme variability in otolith morphology, multiple images are provided. For each species, the scientific and common names, position and size of the otolith pictured, and length and mass of the fish from which the otolith was removed are given. The regression relationships between (1) weight (WT in grams) and fish length (SL in cm) and (2) fish length (SL or FL in cm) and otolith length (OL in mm) are provided for each species. The coefficient of determination is r^2.

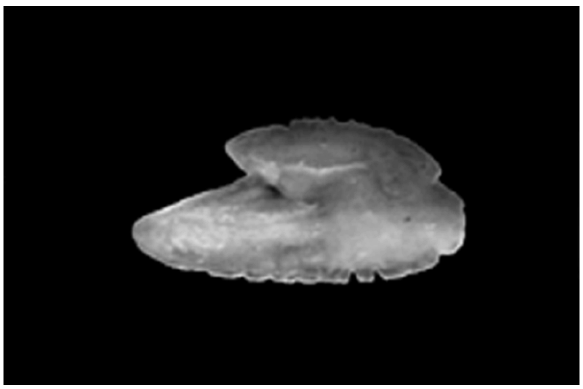
CLUPEIDAE



Alosa sapidissima
(American shad)

Left otolith; length (mm): 3.6
Fish length (cm): 27.3
Fish weight (g): 320.5

Regression equations:
Length: SL = 11.46 (OL) – 11.08 **r^2 = 0.960**
Weight: WT = 0.0135 $SL^{3.046}$ **r^2 = 0.997**

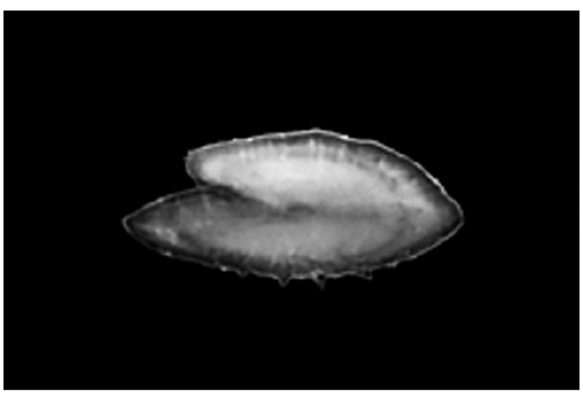


Clupea pallasi
(Pacific herring)

Right otolith; length (mm): 3.3
Fish length (cm): 17.7
Fish weight (g): 71.6

Regression equations:
Length: SL = 5.24 (OL) – 1.85 **r^2 = 0.934**
Weight: WT = 0.0044 $SL^{3.398}$ **r^2 = 0.976**

ENGRAULIDAE



Engraulis mordax
(northern anchovy)

Right otolith; length (mm): 3.5
Fish length (cm): 8.0
Fish weight (g): 7.8

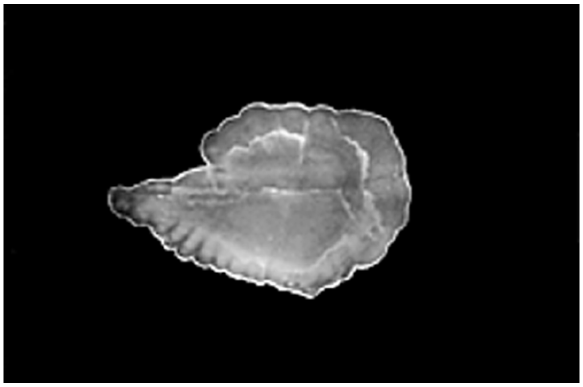
Regression equations:
Length: SL = 2.28 (OL) + 0.85 **r^2 = 0.694**
Weight: WT = 0.0485 $SL^{2.413}$ **r^2 = 0.807**

Engraulis mordax
(northern anchovy)

Left otolith; length (mm): 3.4
Fish length (cm): 11.9
Fish weight (g): 12.8

Regression equations:
Length: SL = 2.28 (OL) + 0.85 **r^2 = 0.694**
Weight: WT = 0.0485 $SL^{2.413}$ **r^2 = 0.807**

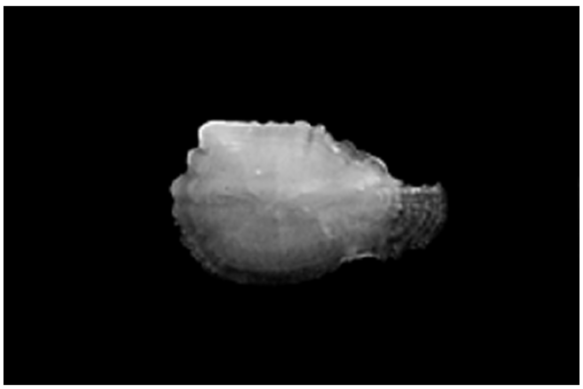
OSMERIDAE



Allosmerus elongatus
(whitebait smelt)

Right otolith; length (mm): 3.0
Fish length (cm): 9.3
Fish weight (g): 5.9

Regression equations:
Length: $SL = 2.11 (OL) + 3.02$ $r^2 = 0.838$
Weight: $WT = 0.0063\ SL^{3.233}$ $r^2 = 0.893$



Hypomesus pretiosus
(surf smelt)

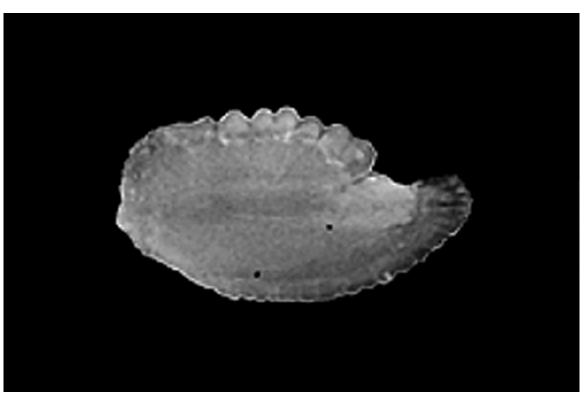
Left otolith; length (mm): 3.8
Fish length (cm): 12.6
Fish weight (g): 20.1

Regression equations:
Length: $SL = 3.61 (OL) – 0.63$ $r^2 = 0.932$
Weight: $WT = 0.0044\ SL^{3.345}$ $r^2 = 0.986$

Mallotus villosus
(capelin)

Right otolith; length (mm): 2.5
Fish length (cm): 11.6
Fish weight (g): 12.0

Regression equations:
Length: $SL = 3.45 (OL) + 3.62$ $r^2 = 0.649$
Weight: $WT = 0.0054\ SL^{3.160}$ $r^2 = 0.717$

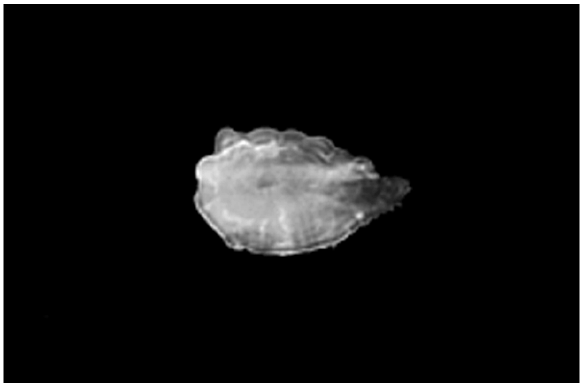


Osmerus mordax
(rainbow smelt)

Left otolith; length (mm): 5.1
Fish length (cm): 13.0
Fish weight (g): 17.9

Regression equations:
Length: $SL = 2.69 (OL) + 0.32$ $r^2 = 0.759$
Weight: $WT = 0.0038\ SL^{3.278}$ $r^2 = 0.819$

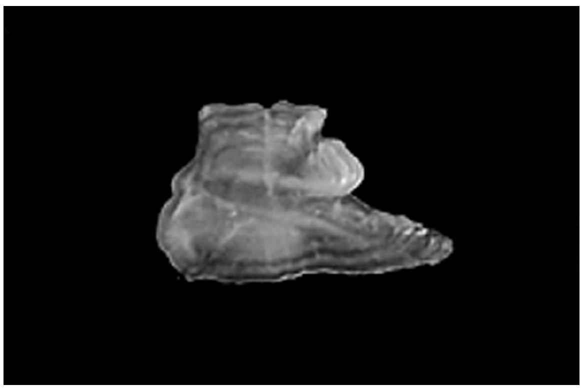
OSMERIDAE (cont.)



Spirinchus thaleichthys
(longfin smelt)

Left otolith; length (mm): 3.8
Fish length (cm): 9.9
Fish weight (g): 8.8

Regression equations:
Length: SL = 2.64 (OL) – 0.20 **r^2 = 0.878**
Weight: WT = 0.0288 $SL^{2.531}$ **r^2 = 0.854**

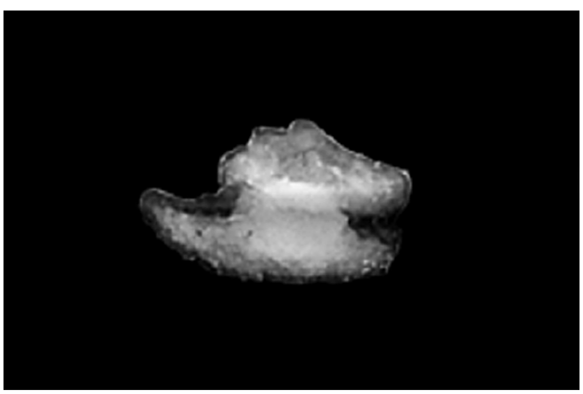


Thaleichthys pacificus
(eulachon)

Left otolith; length (mm): 4.1
Fish length (cm): 16.5
Fish weight (g): 32.7

Regression equations:
Length: SL = 4.71 (OL) – 2.70 **r^2 = 0.871**
Weight: WT = 0.0077 $SL^{3.075}$ **r^2 = 0.884**

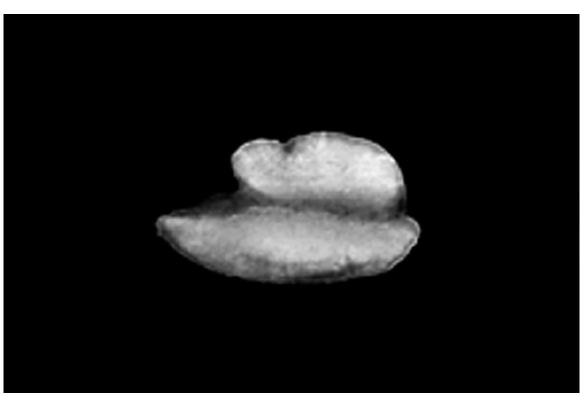
SALMONIDAE



Oncorhynchus kisutch
(coho salmon)

Right otolith; length (mm): 3.7
Fish length (cm): 18.0
Fish weight (g): 98.9

Regression equations:
Length: SL = 16.31 (OL) – 40.74 **r^2 = 0.569**
Weight: WT = 0.0103 $SL^{3.092}$ **r^2 = 0.989**

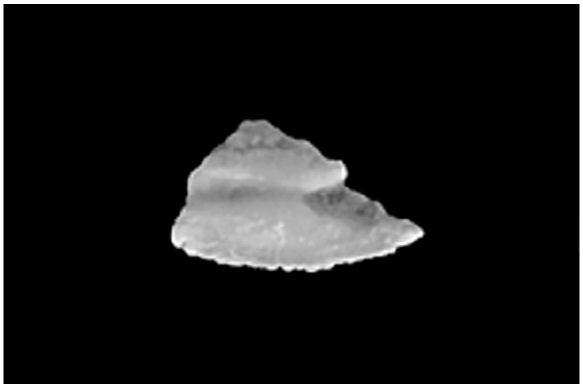


Oncorhynchus kisutch
(coho salmon)

Right otolith; length (mm): 3.3
Fish length (cm): 17.7
Fish weight (g): 66.6

Regression equations:
Length: SL = 16.31 (OL) – 40.74 **r^2 = 0.569**
Weight: WT = 0.0103 $SL^{3.092}$ **r^2 = 0.989**

SALMONIDAE (cont.)



Oncorhynchus mykiss
(rainbow trout)

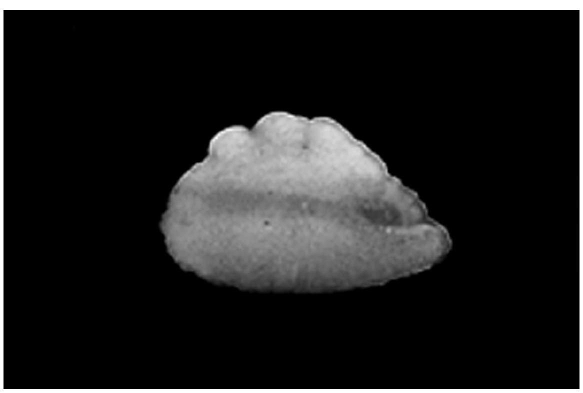
Left otolith; length (mm): 5.0
Fish length (cm): 24.3
Fish weight (g): 320.9

Regression equations:
Length: SL = 16.28 (OL) – 38.14 r^2 **= 0.790**
Weight: WT = 0.0275 SL$^{2.895}$ r^2 **= 0.905**

Oncorhynchus mykiss
(rainbow trout)

Right otolith; length (mm): 4.8
Fish length (cm): 25.3
Fish weight (g): 315.6

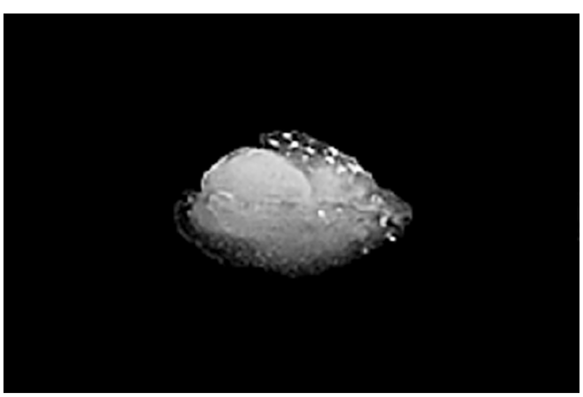
Regression equations:
Length: SL = 16.28 (OL) – 38.14 r^2 **= 0.790**
Weight: WT = 0.0275 SL$^{2.895}$ r^2 **= 0.905**



Oncorhynchus nerka
(sockeye salmon)

Left otolith; length (mm): 3.0
Fish length (cm): 20
Fish weight (g): N/A

Regression equations:
Length: No data available
Weight: No data available



Oncorhynchus tshawytscha
(chinook salmon)

Left otolith; length (mm): 2.4
Fish length (cm): 7.6
Fish weight (g): N/A

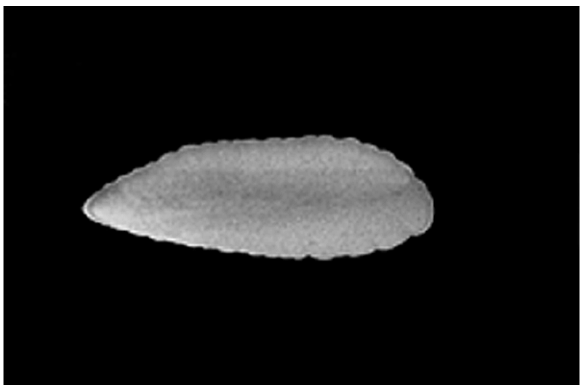
Regression equations:
Length: No data available
Weight: No data available

GADIDAE

Eleginus gracilis
(Saffron cod; ventral view)

Left otolith; length (mm): 6.8
Fish length (cm): 9.2
Fish weight (g): 6.2

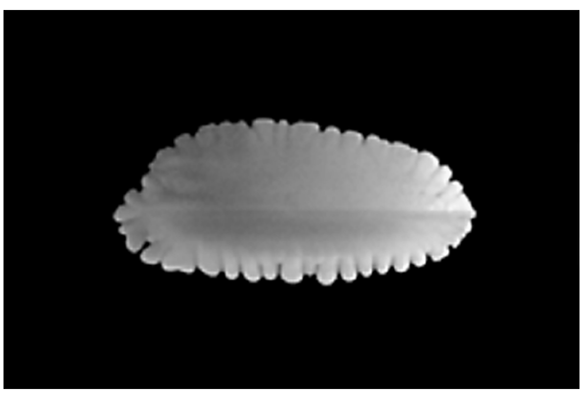
Regression equations:
Length: SL = 1.89 (OL) – 2.76 $r^2 = 0.960$
Weight: WT = 0.0039 SL$^{3.292}$ $r^2 = 0.990$



Eleginus gracilis
(saffron cod)

Left otolith; length (mm): 6.8
Fish length (cm): 9.2
Fish weight (g): 6.2

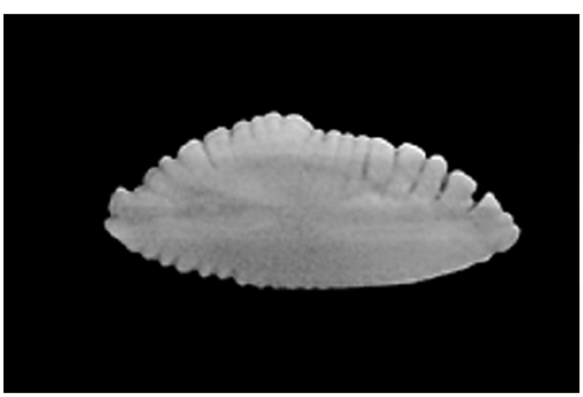
Regression equations:
Length: SL = 1.89 (OL) – 2.76 $r^2 = 0.960$
Weight: WT = 0.0039 SL$^{3.292}$ $r^2 = 0.990$



Gadus macrocephalus
(Pacific cod)

Right otolith; length (mm): 12.0
Fish length (cm): 29.5
Fish weight (g): 373.8

Regression equations:
Length: FL = 4.51 (OL) – 22.97 $r^2 = 0.883$
Weight: No data available

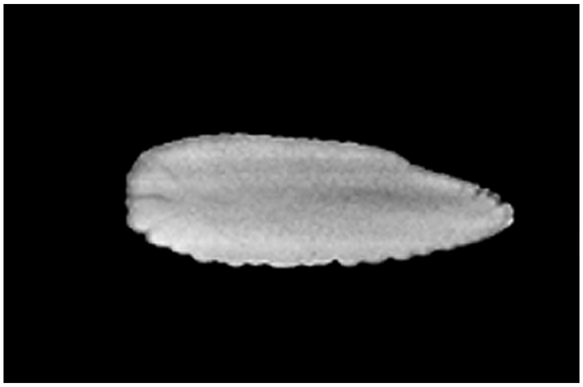


Merluccius productus
(Pacific hake)

Right otolith; length (mm): 22.0
Fish length (cm): 42.0
Fish weight (g): 659.0

Regression equations:
Length: SL = 2.04 (OL) + 0.96 $r^2 = 0.891$
Weight: WT = 0.0081 SL$^{2.966}$ $r^2 = 0.933$

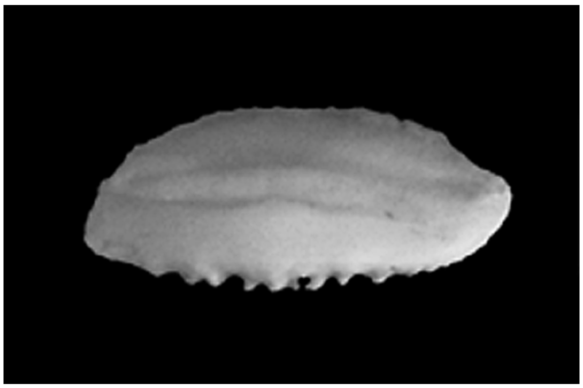
GADIDAE (cont.)



Microgadus proximus
(Pacific tomcod)

Right otolith; length (mm): 12.3
Fish length (cm): 18.2
Fish weight (g): 59.8

Regression equations:
Length: SL = 1.77 (OL) – 3.51 r^2 **= 0.932**
Weight: WT = 0.0064 SL$^{3.191}$ r^2 **= 0.988**

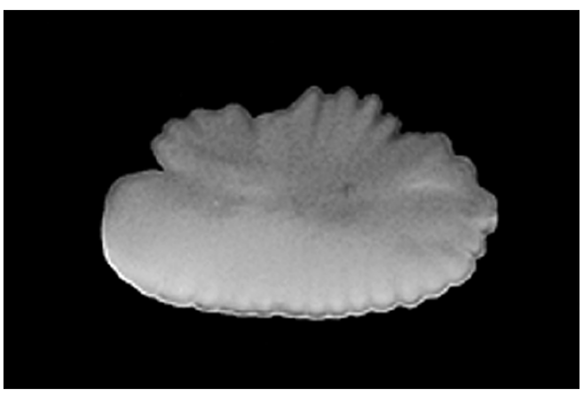


Theragra chalcogramma
(walleye pollock)

Left otolith; length (mm): 16.0
Fish length (cm): 33.5
Fish weight (g): 394.0

Regression equations:
Length: SL = 2.24 (OL) – 2.35 r^2 **= 0.948**
Weight: WT = 0.0043 SL$^{3.255}$ r^2 **= 0.985**

MACROURIDAE

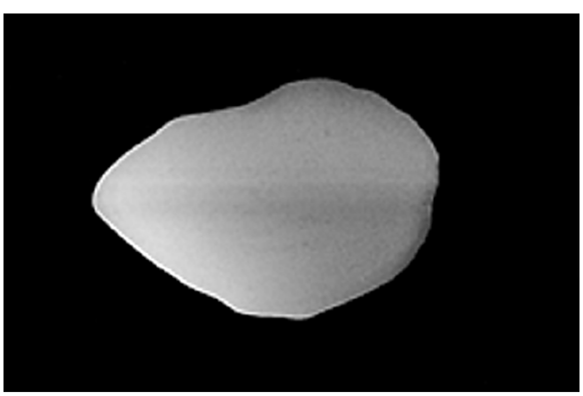


Coryphaenoides acrolepis
(Pacific rattail)

Right otolith; length (mm): 10.0
Fish length (cm): 36.0
Fish weight (g): 148.8

Regression equations:
Length: SL = 3.44 (OL) – 3.23 r^2 **= 0.926**
Weight: WT = 0.0016 SL$^{3.209}$ r^2 **= 0.921**

OPHIDIIDAE

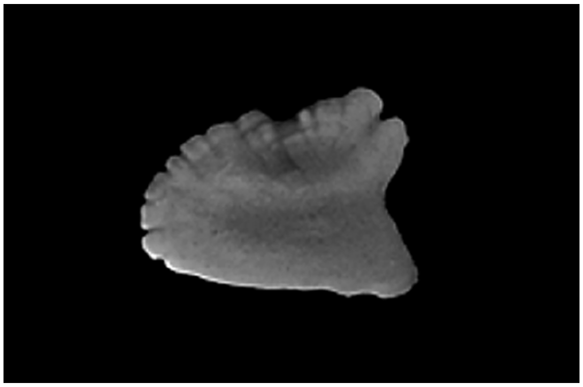


Chilara taylori
(spotted cusk-eel)

Left otolith; length (mm): 7.6
Fish length (cm): 21.8
Fish weight (g): 46.6

Regression equations:
Length: SL = 2.51 (OL) + 2.15 r^2 **= 0.730**
Weight: WT = 0.0004 SL$^{3.761}$ r^2 **= 0.964**

BATRACHOIDIDAE

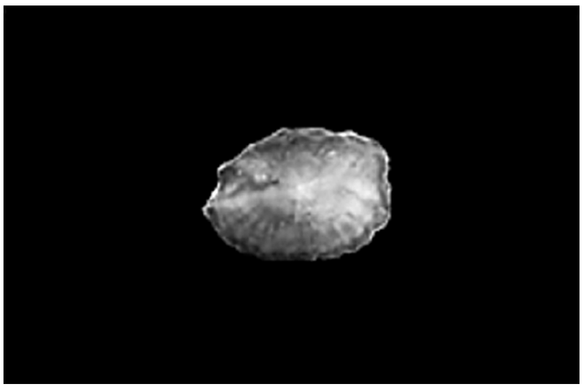


Porichthys notatus
(plainfin midshipman)

Left otolith; length (mm): 9.1
Fish length (cm): 22.5
Fish weight (g): 215.1

Regression equations:
Length: $SL = 2.80\ (OL) - 2.59$ $r^2 = 0.926$
Weight: $WT = 0.0207\ SL^{2.916}$ $r^2 = 0.967$

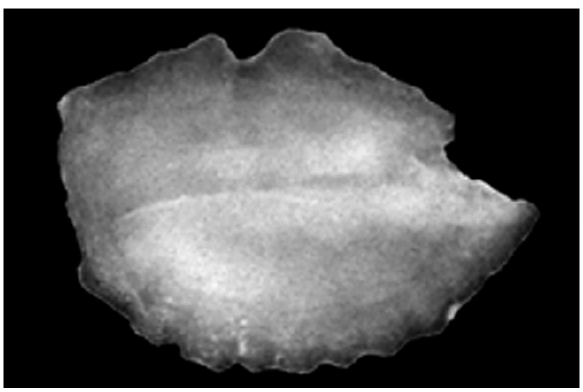
ATHERINIDAE



Atherinops affinis
(topsmelt)

Right otolith; length (mm): 2.4
Fish length (cm): 9.9
Fish weight (g): 10.2

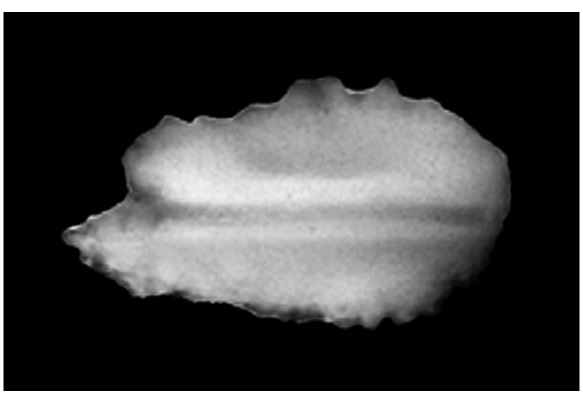
Regression equations:
Length: $SL = 3.72\ (OL) + 0.55$ $r^2 = 0.891$
Weight: $WT = 0.1698\ SL^{1.733}$ $r^2 = 0.429$



Atherinops affinis
(topsmelt)

Left otolith; length (mm): 3.2
Fish length (cm): 11.8
Fish weight (g): 13.2

Regression equations:
Length: $SL = 3.72\ (OL) + 0.55$ $r^2 = 0.891$
Weight: $WT = 0.1698\ SL^{1.733}$ $r^2 = 0.429$

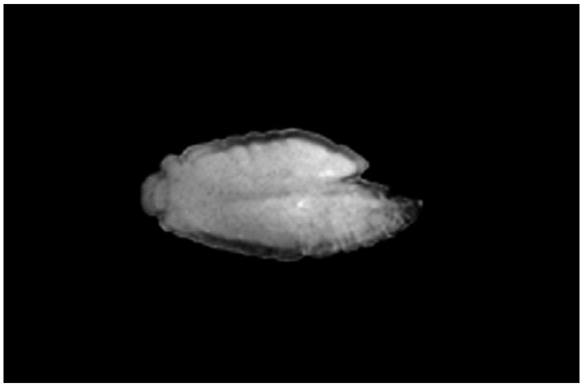


Atherinopsis californiensis
(jacksmelt)

Right otolith; length (mm): 6.1
Fish length (cm): 28.7
Fish weight (g): 260.0

Regression equations:
Length: $SL = 4.85\ (OL) - 2.46$ $r^2 = 0.950$
Weight: $WT = 0.0049\ SL^{3.228}$ $r^2 = 0.968$

SCORPAENIDAE



Sebastes auriculatus
(brown rockfish)

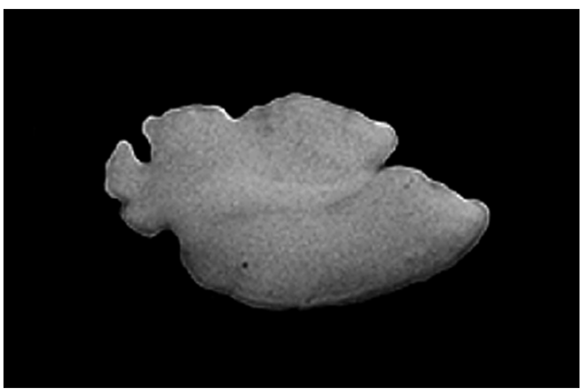
Left otolith; length (mm): 3.2
Fish length (cm): 6.7
Fish weight (g): 6.9

Regression equations:
Length: SL = 3.32 (OL) – 5.30 r^2 **= 0.940**
Weight: No data available

Sebastes constellatus
(starry rockfish)

Right otolith; length (mm): 12.3
Fish length (cm): N/A
Fish weight (g): N/A

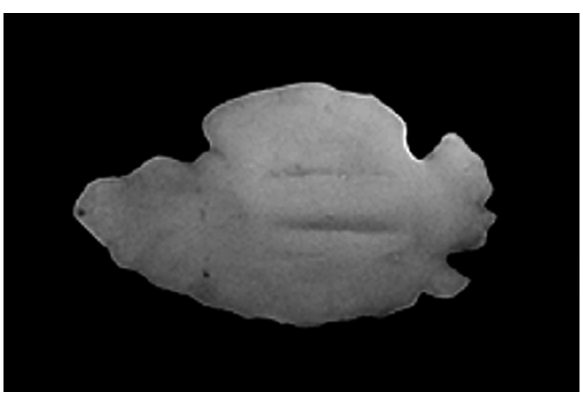
Regression equations:
Length: SL = 2.53 (OL) – 3.75 r^2 **= 0.960**
Weight: No data available



Sebastes crameri
(darkblotched rockfish)

Left otolith; length (mm): 13.9
Fish length (cm): 31.0
Fish weight (g): 1121.5

Regression equations:
Length: SL = 2.81 (OL) – 2.71 r^2 **= 0.940**
Weight: No data available

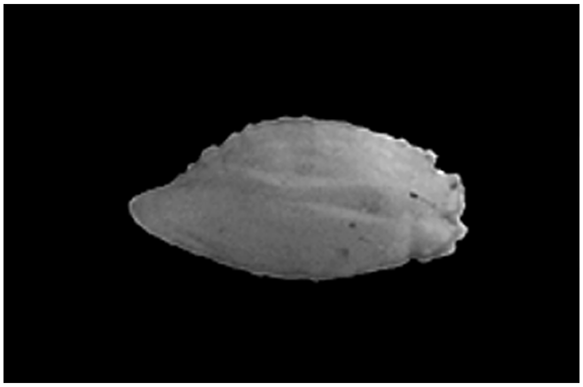


Sebastes diploproa
(splitnose rockfish)

Right otolith; length (mm): 15.1
Fish length (cm): N/A
Fish weight (g): N/A

Regression equations:
Length: SL = 2.26 (OL) – 1.29 r^2 **= 0.960**
Weight: No data available

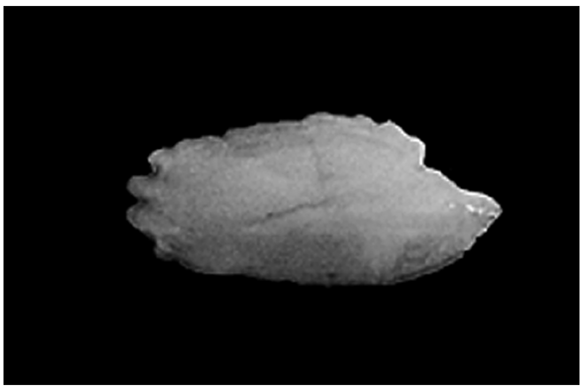
SCORPAENIDAE (cont.)



Sebastes flavidus
(yellowtail rockfish)

Right otolith; length (mm): 12.2
Fish length (cm): 24.5
Fish weight (g): N/A

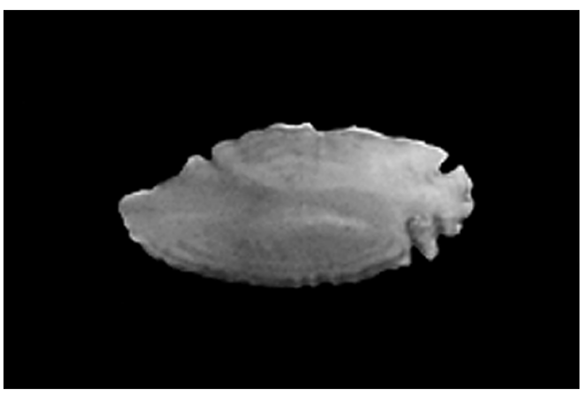
Regression equations:
Length: SL = 2.65 (OL) – 1.09 **r^2 = 0.880**
Weight: No data available



Sebastes maliger
(quillback rockfish)

Left otolith; length (mm): 13.0
Fish length (cm): 32.5
Fish weight (g): N/A

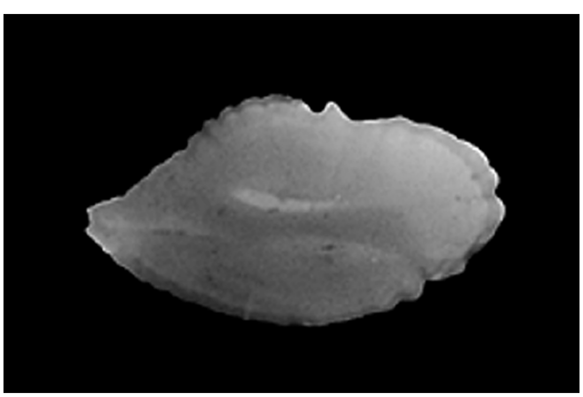
Regression equations:
Length: SL = 2.99 (OL) – 5.31 **r^2 = 0.860**
Weight: No data available



Sebastes melanops
(black rockfish)

Right otolith; length (mm): 12.4
Fish length (cm): 29.0
Fish weight (g): N/A

Regression equations:
Length: SL = 2.23 (OL) – 1.48 **r^2 = 0.749**
Weight: $WT = 0.1225\ SL^{2.499}$ **r^2 = 0.585**

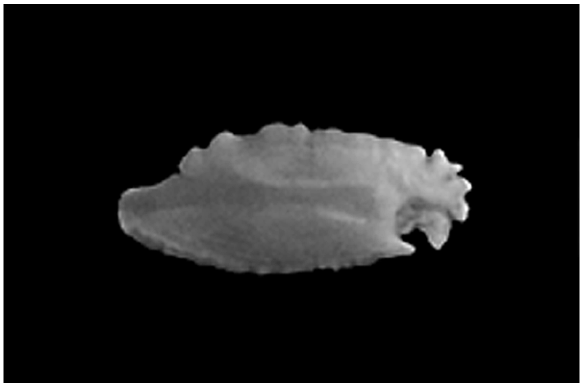


Sebastes miniatus
(vermillion rockfish)

Right otolith; length (mm): 15.1
Fish length (cm): 35.5
Fish weight (g): N/A

Regression equations:
Length: SL = 2.94 (OL) – 5.67 **r^2 = 0.930**
Weight: No data available

SCORPAENIDAE (cont.)



Sebastes mystinus
(blue rockfish)

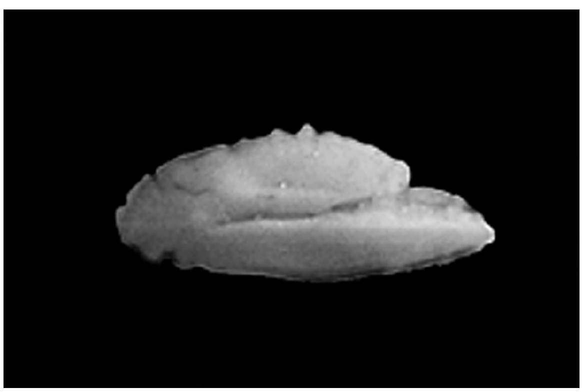
Right otolith; length (mm): 12.8
Fish length (cm): 29.0
Fish weight (g): N/A

Regression equations:
Length: SL = 2.98 (OL) – 1.82 r^2 **= 0.830**
Weight: No data available

Sebastes nebulosus
(China rockfish)

Right otolith; length (mm): 10.7
Fish length (cm): N/A
Fish weight (g): N/A

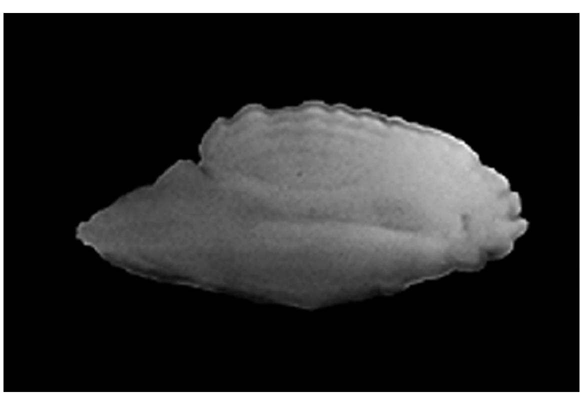
Regression equations:
Length: SL = 2.52 (OL) + 3.30 r^2 **= 0.790**
Weight: No data available



Sebastes paucispinis
(boccacio)

Left otolith; length (mm): 14.0
Fish length (cm): 39.8
Fish weight (g): 1191.8

Regression equations:
Length: SL = 2.41 (OL) + 0.14 r^2 **= 0.769**
Weight: No data available

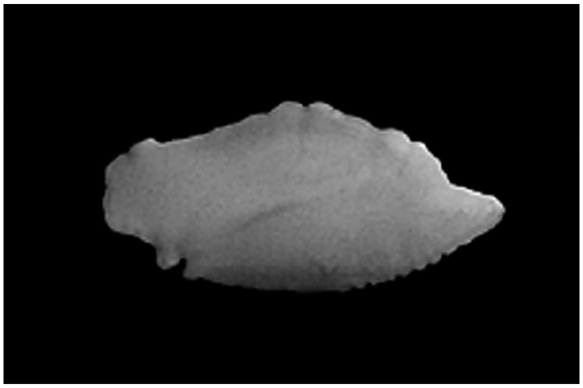


Sebastes pinniger
(canary rockfish)

Right otolith; length (mm): 16.3
Fish length (cm): 31.8
Fish weight (g): N/A

Regression equations:
Length: SL = 2.94 (OL) – 8.51 r^2 **= 0.920**
Weight: No data available

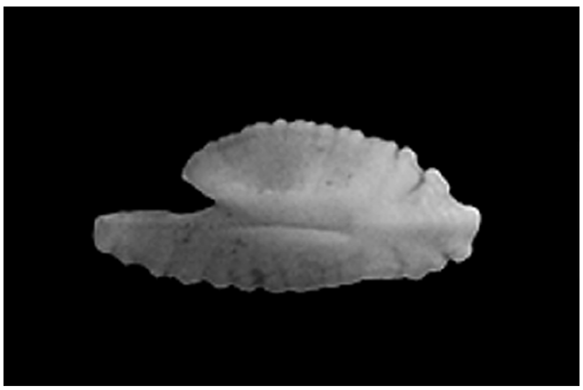
SCORPAENIDAE (cont.)



Sebastes ruberrimus
(yellow eye rockfish)

Left otolith; length (mm): 14.4
Fish length (cm): 34.0
Fish weight (g): N/A

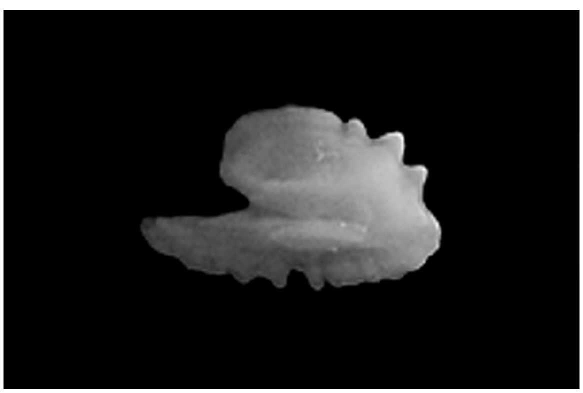
Regression equations:
Length: SL = 3.13 (OL) – 7.62 $r^2 = 0.920$
Weight: No data available



Sebastolobus alascanus
(shortspine thornyhead)

Right otolith; length (mm): 14.1
Fish length (cm): 27.7
Fish weight (g): 515.6

Regression equations:
Length: SL = 2.31 (OL) – 3.71 $r^2 = 0.828$
Weight: $WT = 0.0102\ SL^{3.239}$ $r^2 = 0.988$

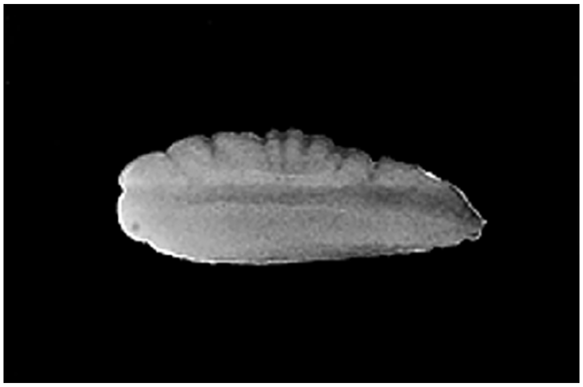


Sebastolobus altivelis
(longspine thornyhead)

Right otolith; length (mm): 10.9
Fish length (cm): 24.5
Fish weight (g): 328.8

Regression equations:
Length: SL = 4.94 (OL) – 27.50 $r^2 = 0.839$
Weight: $WT = 0.0155\ SL^{3.113}$ $r^2 = 0.997$

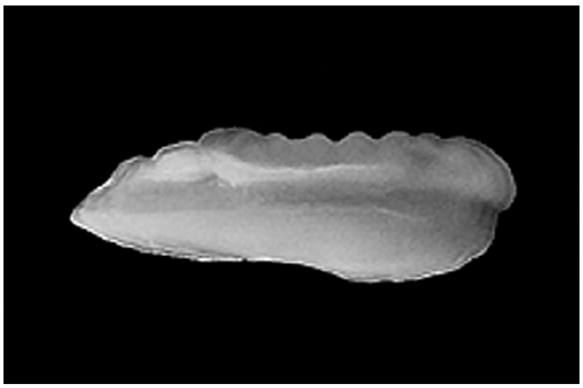
ANOPLOPOMATIDAE



Anoplopoma fimbria
(sablefish)

Left otolith; length (mm): 6.2
Fish length (cm): 36.4
Fish weight (g): 541.7

Regression equations:
Length: **SL = 5.28 (OL) + 1.62** $r^2 = 0.955$
Weight: **WT =** $0.0163\ SL^{2.902}$ $r^2 = 0.993$

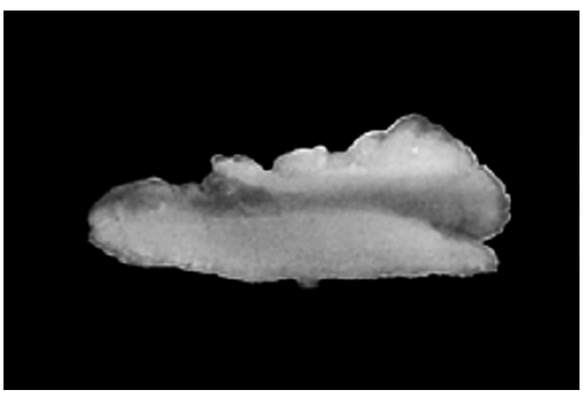


Anoplopoma fimbria
(sablefish)

Right otolith; length (mm): 7.7
Fish length (cm): 41.6
Fish weight (g): 868.1

Regression equations:
Length: **SL = 5.28 (OL) + 1.62** $r^2 = 0.955$
Weight: **WT =** $0.0163\ SL^{2.902}$ $r^2 = 0.993$

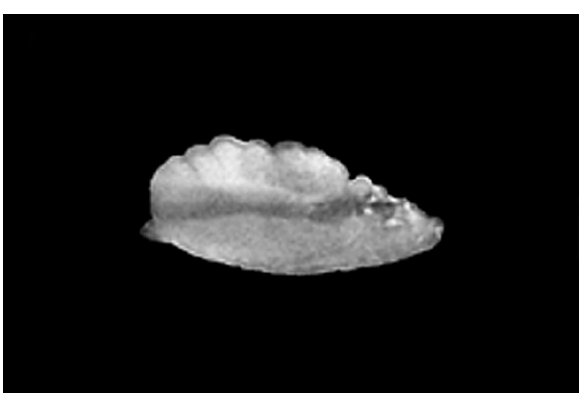
HEXAGRAMMIDAE



Ophiodon elongatus
(lingcod)

Right otolith; length (mm): 9.1
Fish length (cm): 62.0
Fish weight (g): N/A

Regression equations:
Length: **SL = 8.23 (OL) – 8.20** $r^2 = 0.722$
Weight: **WT =** $0.0023\ SL^{3.567}$ $r^2 = 0.620$

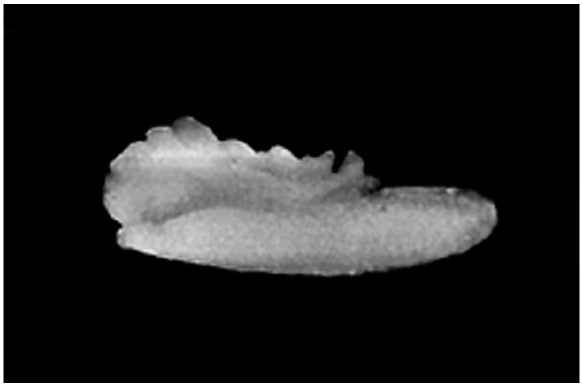


Ophiodon elongatus
(lingcod)

Left otolith; length (mm): 5.3
Fish length (cm): 38.2
Fish weight (g): N/A

Regression equations:
Length: **SL = 8.23 (OL) – 8.20** $r^2 = 0.722$
Weight: **WT =** $0.0023\ SL^{3.567}$ $r^2 = 0.620$

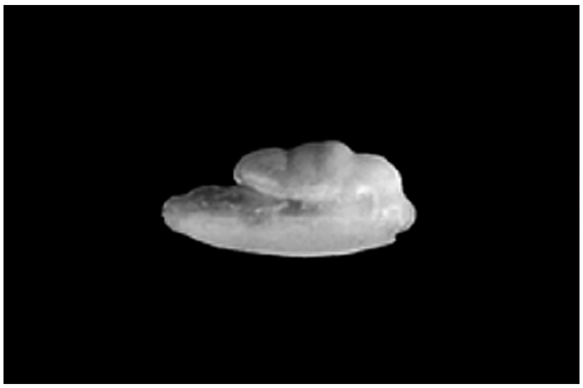
HEXAGRAMMIDAE (cont.)



Ophiodon elongatus
(lingcod)

Left otolith; length (mm): 9.0
Fish length (cm): 62.0
Fish weight (g): N/A

Regression equations:
Length: SL = 8.23 (OL) – 8.20 $r^2 = 0.722$
Weight: WT = 0.0023 $SL^{3.567}$ $r^2 = 0.620$

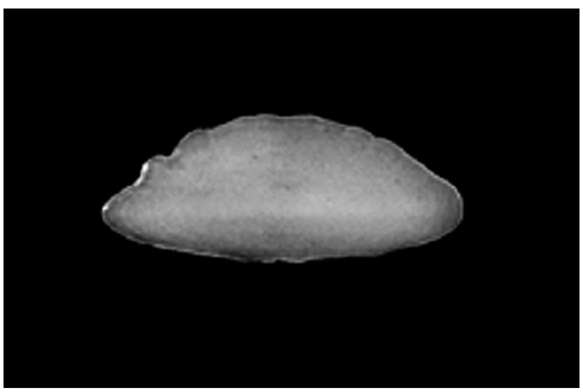


Pleurogrammus monopterygius
(Atka mackerel)

Right otolith; length (mm): 3.5
Fish length (cm): 21.2
Fish weight (g): 108.8

Regression equations:
Length: FL = 8.40 (OL) – 4.99 $r^2 = 0.864$
Weight: WT = 0.0034 $FL^{3.401}$ $r^2 = 0.987$

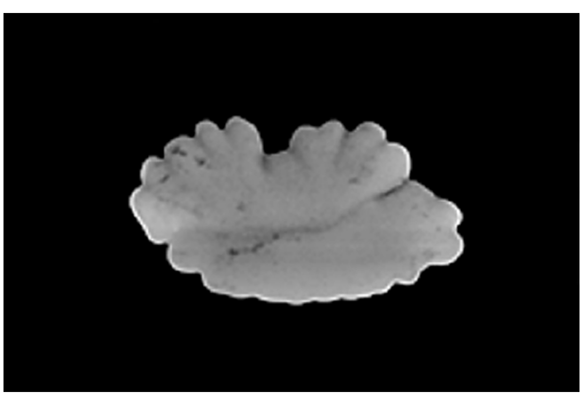
COTTIDAE



Chitonotus pugetensis
(roughback sculpin)

Right otolith; length (mm): 2.9
Fish length (cm): 6.0
Fish weight (g): 3.3

Regression equations:
Length: SL = 3.37 (OL) – 4.52 $r^2 = 0.857$
Weight: WT = 0.0217 $SL^{2.871}$ $r^2 = 0.960$

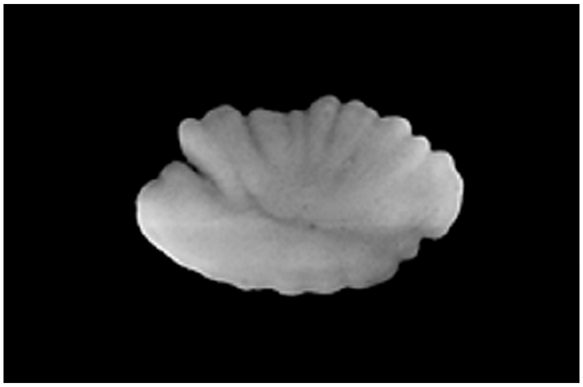


Dasycottus setiger
(spinyhead sculpin)

Left otolith; length (mm): 8.5
Fish length (cm): N/A
Fish weight (g): N/A

Regression equations:
Length: FL = 3.11 (OL) – 7.03 $r^2 = 0.655$
Weight: No data available

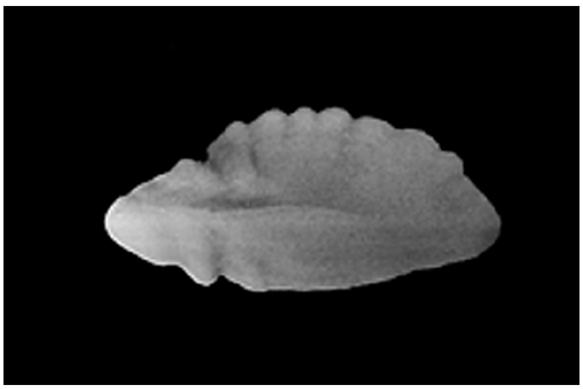
COTTIDAE (cont.)



Dasycottus setiger
(spinyhead sculpin)

Right otolith; length (mm): 8.3
Fish length (cm): N/A
Fish weight (g): N/A

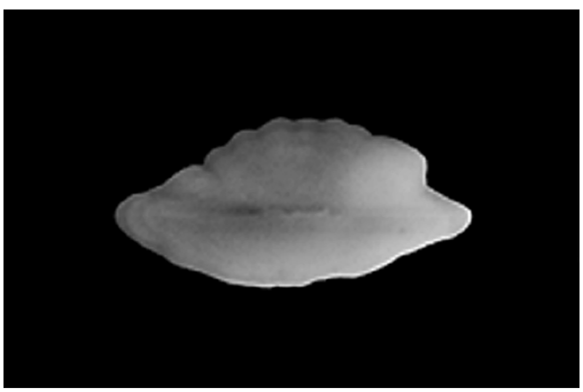
Regression equations:
Length: FL = 3.11 (OL) – 7.03 r^2 **= 0.655**
Weight: No data available



Gymnocanthus galeatus
(armorhead sculpin)

Right otolith; length (mm): 6.6
Fish length (cm): 13.4
Fish weight (g): 43.5

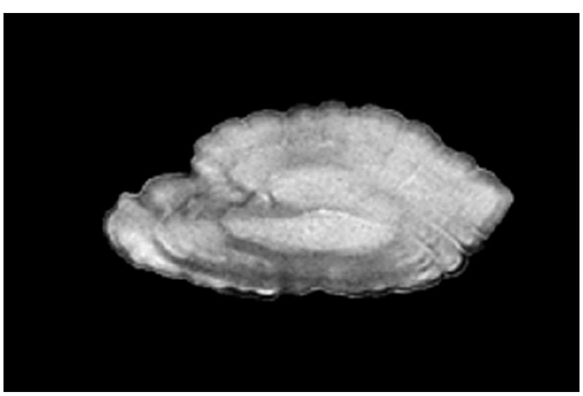
Regression equations:
Length: SL = 1.75 (OL) + 0.82 r^2 **= 0.476**
Weight: $WT = 0.0100\ SL^{3.196}$ r^2 **= 0.939**



Gymnocanthus galeatus
(armorhead sculpin)

Right otolith; length (mm): 6.5
Fish length (cm): 11.3
Fish weight (g): 22.4

Regression equations:
Length: SL = 1.75 (OL) + 0.82 r^2 **= 0.476**
Weight: $WT = 0.0100\ SL^{3.196}$ r^2 **= 0.939**

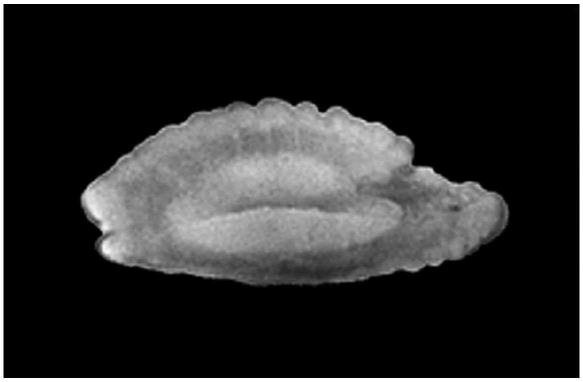


Leptocottus armatus
(Pacific staghorn sculpin)

Right otolith; length (mm): 5.2
Fish length (cm): 11.5
Fish weight (g): 30.5

Regression equations:
Length: SL = 2.58 (OL) – 2.26 r^2 **= 0.928**
Weight: $WT = 0.0111\ SL^{3.229}$ r^2 **= 0.990**

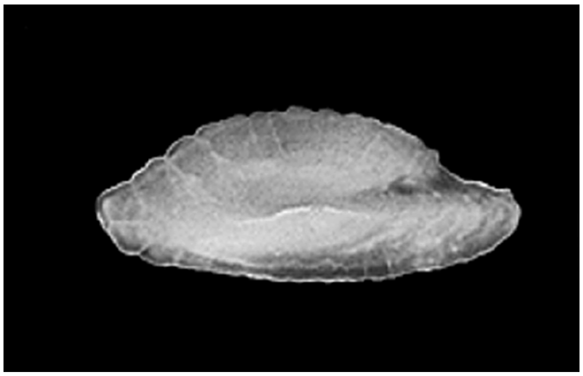
COTTIDAE (cont.)



Leptocottus armatus
(Pacific staghorn sculpin)

Left otolith; length (mm): 5.8
Fish length (cm): 13.6
Fish weight (g): 46.5

Regression equations:
Length: SL = 2.58 (OL) – 2.26 r^2 **= 0.928**
Weight: WT = 0.0111 $SL^{3.229}$ r^2 **= 0.990**

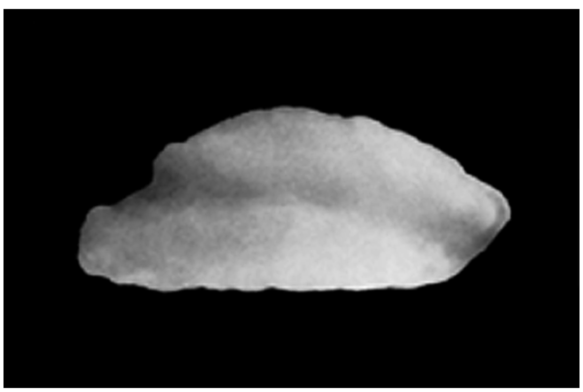


Leptocottus armatus
(Pacific staghorn sculpin)

Left otolith; length (mm): 6.1
Fish length (cm): 13.5
Fish weight (g): 47.8

Regression equations:
Length: SL = 2.58 (OL) – 2.26 r^2 **= 0.928**
Weight: WT = 0.0111 $SL^{3.229}$ r^2 **= 0.990**

AGONIDAE



Podothecus acipenserinus
(sturgeon poacher)

Right otolith; length (mm): 4.2
Fish length (cm): 19.1
Fish weight (g): 54.0

Regression equations:
Length: SL = 6.58 (OL) – 6.21 r^2 **= 0.840**
Weight: WT = 0.0030 $SL^{3.233}$ r^2 **= 0.956**

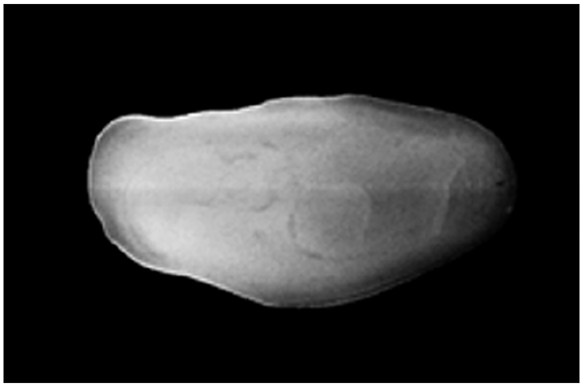
CARANGIDAE

Trachurus symmetricus
(Jack mackerel)

Right otolith; length (mm): 7.6
Fish length (cm): 26.8
Fish weight (g): 266.0

Regression equations:
Length: Not significant r^2 **= 0.141**
Weight: WT = 0.0635 $SL^{2.556}$ r^2 **= 0.761**

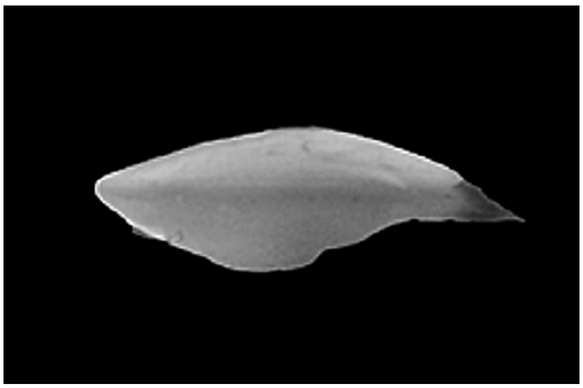
SCIAENIDAE



Genyonemus lineatus
(white croaker)

Left otolith; length (mm): 10.2
Fish length (cm): 20.5
Fish weight (g): 171.8

Regression equations:
Length: SL = 1.52 (OL) + 4.66 **r^2 = 0.534**
Weight: WT = 0.0550 $SL^{2.700}$ **r^2 = 0.767**

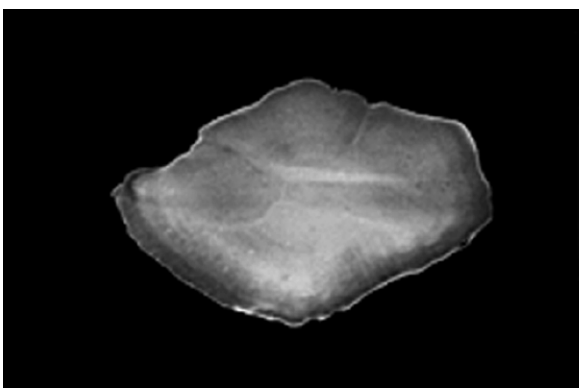


***Genyonemus lineatus* (lateral view)**
(white croaker)

Left otolith; length (mm): 10.2
Fish length (cm): 20.5
Fish weight (g): 171.8

Regression equations:
Length: SL = 1.52 (OL) + 4.66 **r^2 = 0.534**
Weight: WT = 0.0550 $SL^{2.700}$ **r^2 = 0.767**

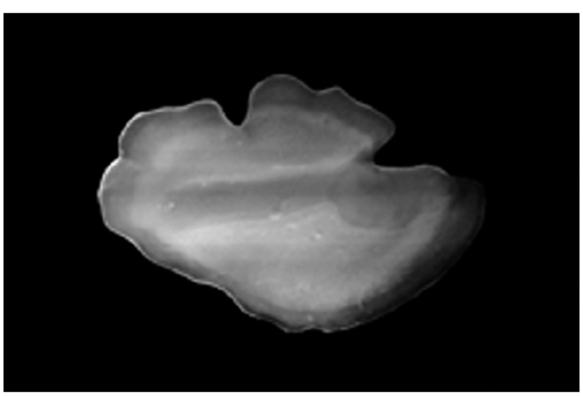
EMBIOTOCIDAE



Cymatogaster aggregata
(shiner perch)

Right otolith; length (mm): 6.3
Fish length (cm): 10.1
Fish weight (g): 35.7

Regression equations:
Length: SL = 1.74 (OL) – 0.52 **r^2 = 0.925**
Weight: WT = 0.0100 $SL^{3.515}$ **r^2 = 0.979**

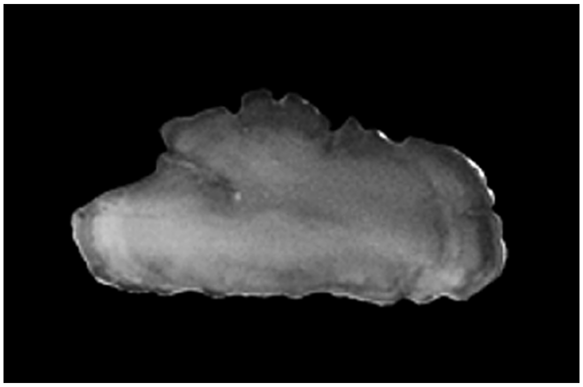


Cymatogaster aggregata
(shiner perch)

Left otolith; length (mm): 6.3
Fish length (cm): 10.7
Fish weight (g): 38.6

Regression equations:
Length: SL = 1.74 (OL) – 0.52 **r^2 = 0.925**
Weight: WT = 0.0100 $SL^{3.515}$ **r^2 = 0.979**

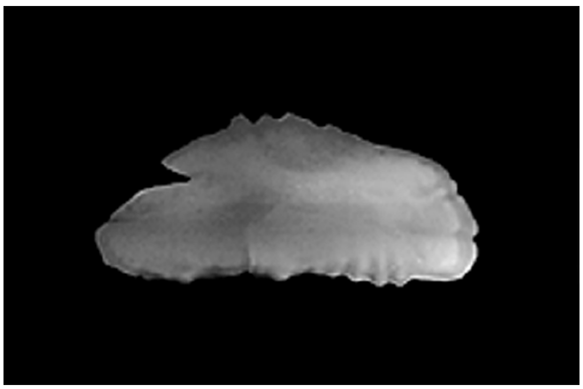
EMBIOTOCIDAE (cont.)



Embiotoca jacksoni
(black perch)

Right otolith; length (mm): 7.4
Fish length (cm): 15.6
Fish weight (g): 169.0

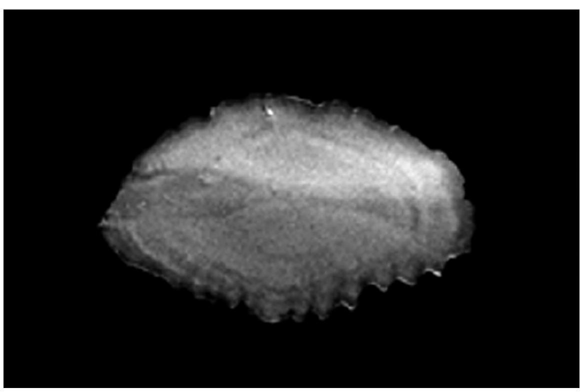
Regression equations:
Length: SL = 2.45 (OL) – 2.61 **r^2 = 0.947**
Weight: WT = 0.0282 $SL^{3.148}$ **r^2 = 0.992**



Embiotoca lateralis
(striped seaperch)

Right otolith; length (mm): 10.5
Fish length (cm): 24.2
Fish weight (g): 540.2

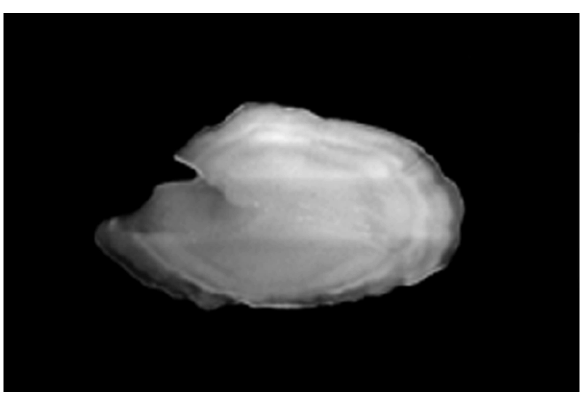
Regression equations:
Length: SL = 2.90 (OL) – 5.68 **r^2 = 0.990**
Weight: WT = 0.0329 $SL^{3.043}$ **r^2 = 0.998**



Hyperprosopon argenteum
(walleye surfperch)

Right otolith; length (mm): 7.9
Fish length (cm): 18.7
Fish weight (g): 213.0

Regression equations:
Length: SL = 2.57 (OL) – 2.83 **r^2 = 0.987**
Weight: WT = 0.0116 $SL^{3.361}$ **r^2 = 0.996**

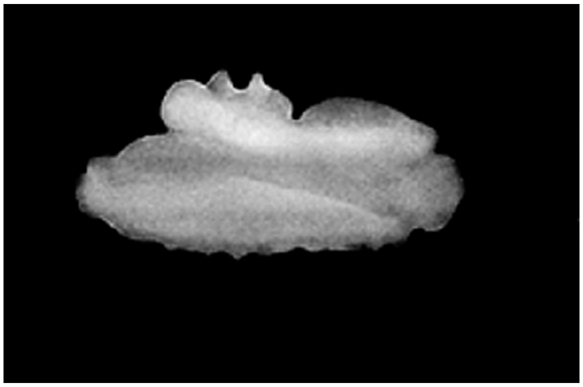


Phanerodon furcatus
(white seaperch)

Right otolith; length (mm): 8.7
Fish length (cm): 23.5
Fish weight (g): 402.2

Regression equations:
Length: SL = 2.33 (OL) – 2.15 **r^2 = 0.912**
Weight: WT = 0.0213 $SL^{3.086}$ **r^2 = 0.997**

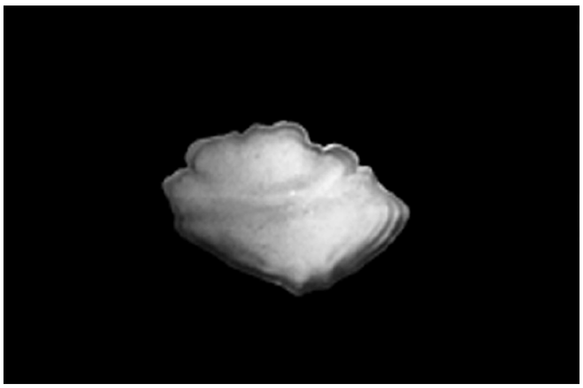
EMBIOTOCIDAE (cont.)



Rhacochilus vacca
(pile perch)

Right otolith; length (mm): 11.8
Fish length (cm): 31.2
Fish weight (g): 1326.40

Regression equations:
Length: SL = 3.35 (OL) – 8.19 **r^2 = 0.965**
Weight: WT = 0.0182 $SL^{3.218}$ **r^2 = 0.997**

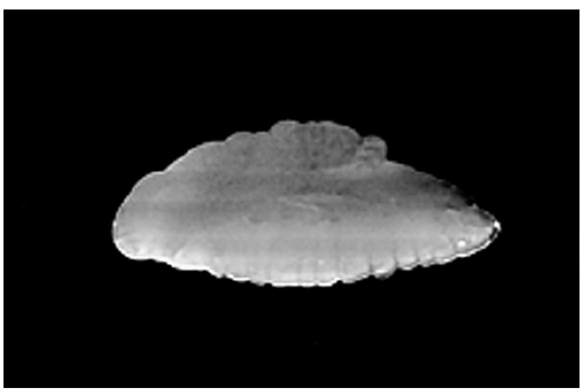


Zalembius rosaceus
(pink seaperch)

Left otolith; length (mm): 4.7
Fish length (cm): 8.9
Fish weight (g): 19.0

Regression equations:
Length: SL = 1.88 (OL) – 0.07 **r^2 = 0.912**
Weight: WT = 0.0199 $SL^{3.102}$ **r^2 = 0.841**

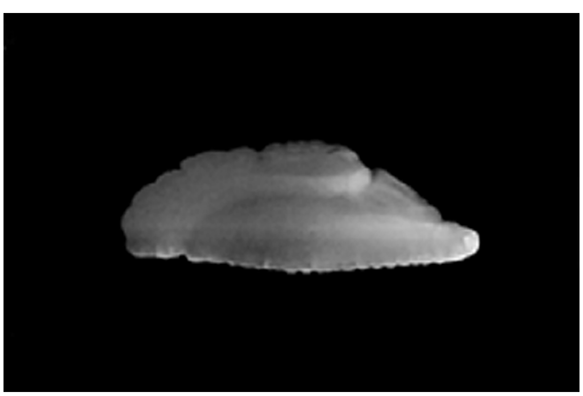
BATHYMASTERIDAE



Bathymaster signatus
(searcher)

Left otolith; length (mm): 6.3
Fish length (cm): 21.0
Fish weight (g): 150.3

Regression equations:
Length: SL = 3.48 (OL) + 1.90 **r^2 = 0.883**
Weight: WT = 0.0038 $SL^{3.256}$ **r^2 = 0.991**

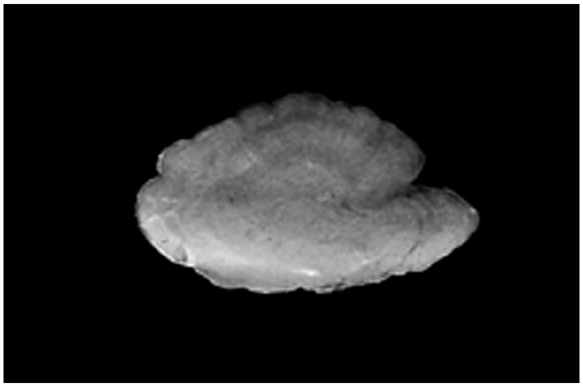


Bathymaster signatus
(searcher)

Left otolith; length (mm): 6.9
Fish length (cm): 23.3
Fish weight (g): 212.9

Regression equations:
Length: SL = 3.48 (OL) + 1.90 **r^2 = 0.883**
Weight: WT = 0.0038 $SL^{3.256}$ **r^2 = 0.991**

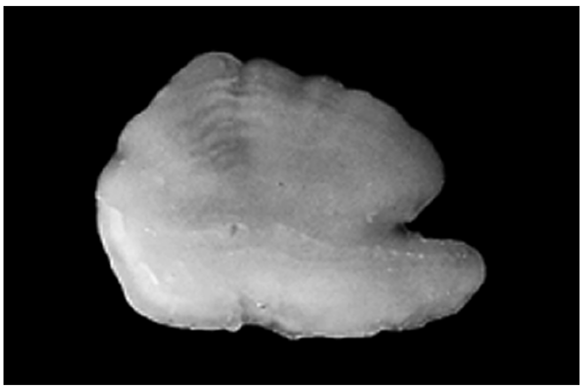
ZOARCIDAE



Lycodes brevipes (shortfin eelpout)

Left otolith; length (mm): 5.1
Fish length (cm): 24.0
Fish weight (g): 61.3

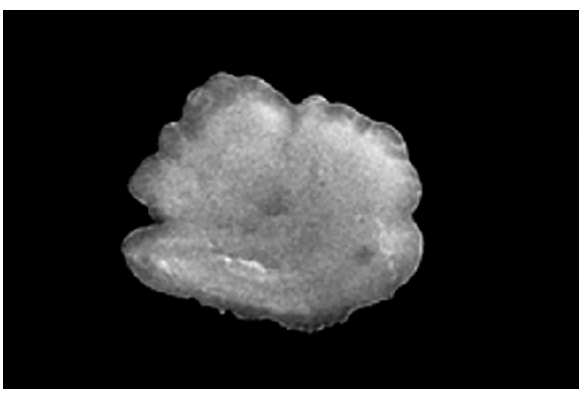
Regression equations:
Length: FL = 3.47 (OL) + 4.83 **r^2 = 0.520**
Weight: WT = 0.0195 $FL^{2.522}$ **r^2 = 0.826**



Lycodes cortezianus (bigfin eelpout)

Left otolith; length (mm): 4.9
Fish length (cm): 38.5
Fish weight (g): 286.8

Regression equations:
Length: SL = 10.96 (OL) – 21.82 **r^2 = 0.742**
Weight: WT = 0.0018 $SL^{3.245}$ **r^2 = 0.993**

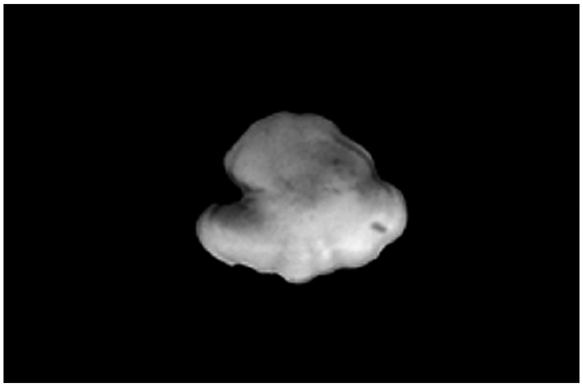


Lycodopsis pacifica (blackbelly eelpout)

Right otolith; length (mm): 3.6
Fish length (cm): 19.5
Fish weight (g): 30.6

Regression equations:
Length: SL = 3.82 (OL) + 4.89 **r^2 = 0.610**
Weight: WT = 0.0018 $SL^{3.302}$ **r^2 = 0.954**

TRICHODONTIDAE

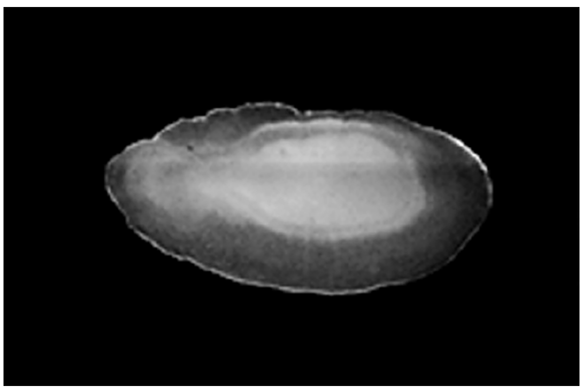


Trichodon trichodon
(Pacific sandfish)

Right otolith; length (mm): 4.0
Fish length (cm): N/A
Fish weight (g): N/A

Regression equations:
Length: FL = 6.06 (OL) – 4.57 $r^2 = 0.684$
Weight: WT = 0.0170 $FL^{2.953}$ $r^2 = 0.971$

AMMODYTIDAE

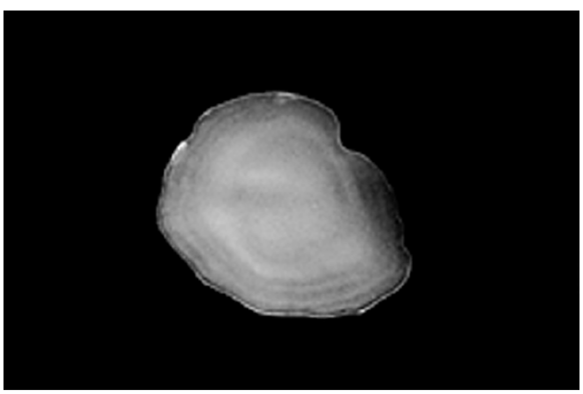


Ammodytes hexapterus
(Pacific sand lance)

Right otolith; length (mm): 2.4
Fish length (cm): 11.7
Fish weight (g): 6.4

Regression equations:
Length: SL = 4.06 (OL) + 2.01 $r^2 = 0.433$
Weight: WT = 0.0063 $SL^{2.790}$ $r^2 = 0.913$

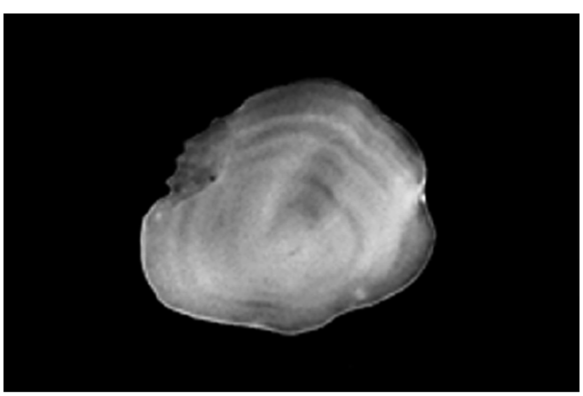
BOTHIDAE



Citharichthys sordidus
(Pacific sanddab)

Left otolith; length (mm): 6.3
Fish length (cm): 23.0
Fish weight (g): 175.8

Regression equations:
Length: SL = 2.87 (OL) + 3.29 $r^2 = 0.727$
Weight: WT = 0.0352 $SL^{2.710}$ $r^2 = 0.851$

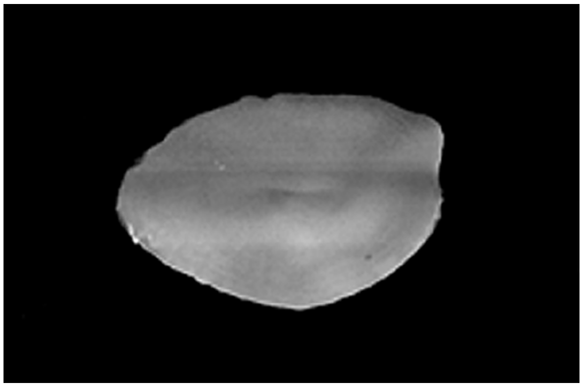


Citharichthys sordidus
(Pacific sanddab)

Right otolith; length (mm): 5.8
Fish length (cm): 20.6
Fish weight (g): 119.5

Regression equations:
Length: SL = 2.87 (OL) + 3.29 $r^2 = 0.727$
Weight: WT = 0.0352 $SL^{2.710}$ $r^2 = 0.851$

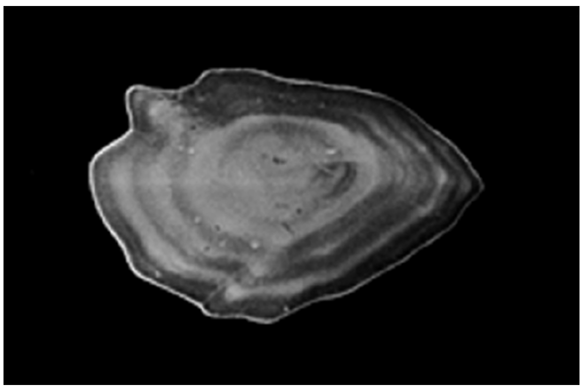
PLEURONECTIDAE



Atheresthes stomias
(arrowtooth flounder)

Right otolith; length (mm): 9.0
Fish length (cm): 37.5
Fish weight (g): 662.6

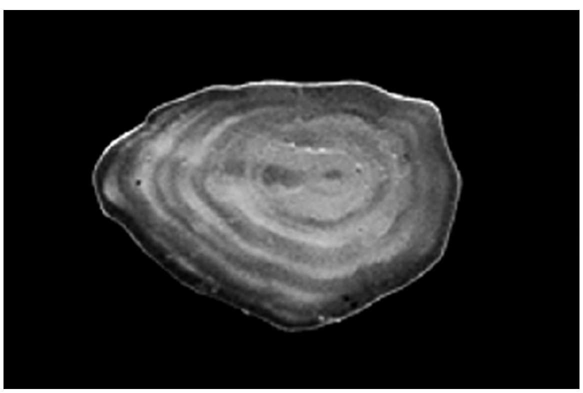
Regression equations:
Length: $FL = 4.75 (OL) - 2.96$ $r^2 = 0.925$
Weight: $WT = 0.0093 FL^{2.999}$ $r^2 = 0.961$



Eopsetta exilis
(slender sole)

Left otolith; length (mm): 4.6
Fish length (cm): 19.6
Fish weight (g): 95.4

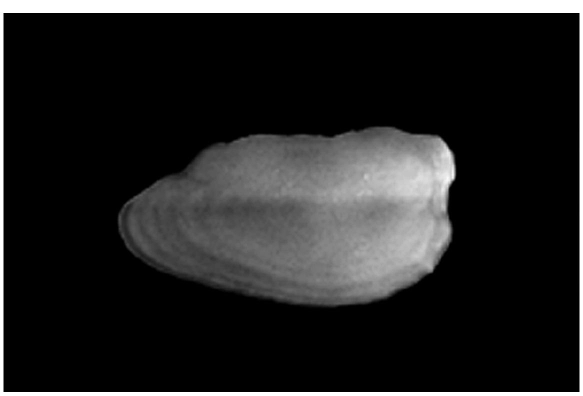
Regression equations:
Length: $SL = 3.37 (OL) + 1.08$ $r^2 = 0.771$
Weight: $WT = 0.0058 SL^{3.293}$ $r^2 = 0.974$



Eopsetta exilis
(slender sole)

Right otolith; length (mm): 4.6
Fish length (cm): 18.5
Fish weight (g): 61.0

Regression equations:
Length: $SL = 3.37 (OL) + 1.08$ $r^2 = 0.771$
Weight: $WT = 0.0058 SL^{3.293}$ $r^2 = 0.974$

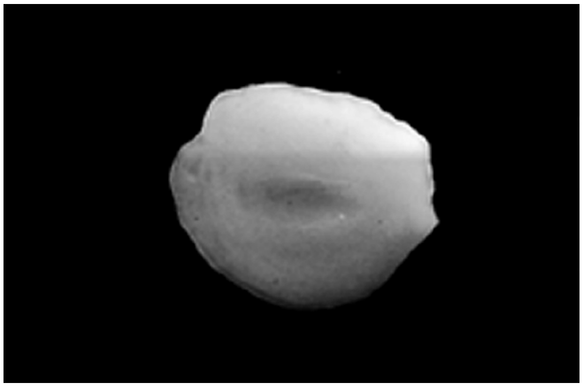


Eopsetta jordani
(petrale sole)

Right otolith; length (mm): 7.3
Fish length (cm): 29.0
Fish weight (g): 502.7

Regression equations:
Length: $SL = 4.85 (OL) - 4.81$ $r^2 = 0.857$
Weight: $WT = 0.0086 SL^{3.231}$ $r^2 = 0.986$

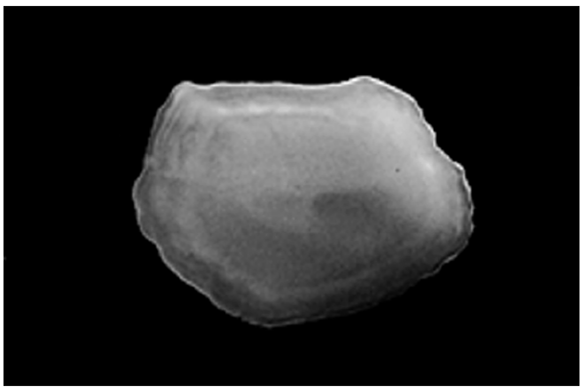
PLEURONECTIDAE (cont.)



Errex zachirus
(rex sole)

Right otolith; length (mm): 6.6
Fish length (cm): 27.2
Fish weight (g): 171.0

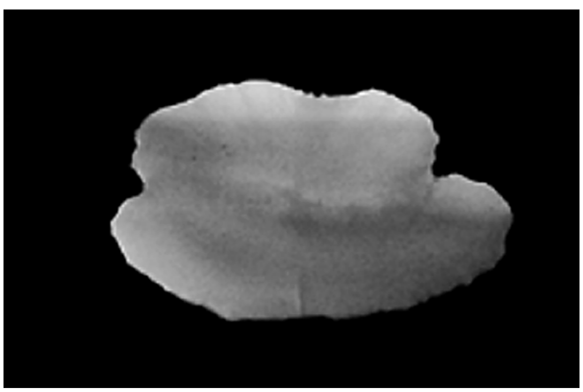
Regression equations:
Length: SL = 4.80 (OL) – 2.50 r^2 **= 0.869**
Weight: WT = 0.0238 $SL^{2.692}$ r^2 **= 0.932**



Hippoglossoides elassodon
(flathead sole)

Left otolith; length (mm): 5.5
Fish length (cm): 19.1
Fish weight (g): 117.3

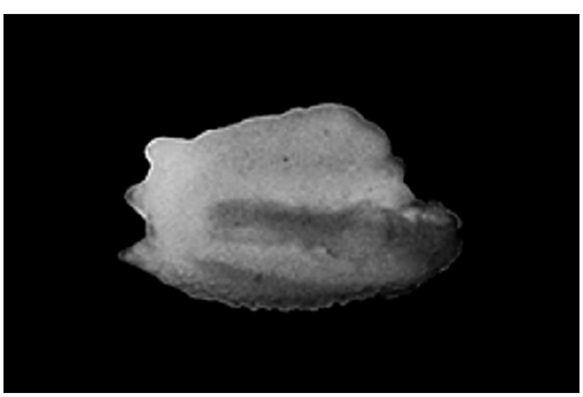
Regression equations:
Length: FL = 4.63 (OL) – 0.71 r^2 **= 0.947**
Weight: WT = 0.0078 $FL^{3.041}$ r^2 **= 0.984**



Hippoglossus stenolepis
(Pacific halibut)

Left otolith; length (mm): 12.8
Fish length (cm): 80.0
Fish weight (g): 6,600.0

Regression equations:
Length: No data available
Weight: No data available

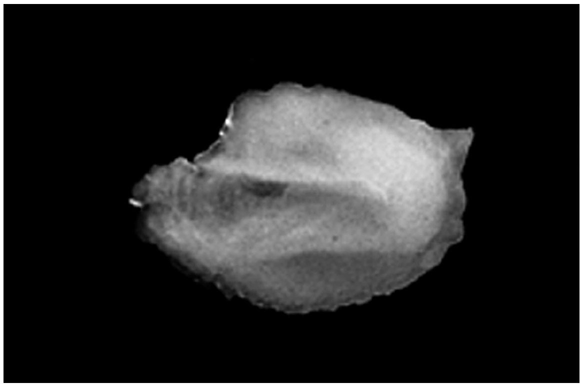


Hypsopsetta guttulata
(diamond turbot)

Left otolith; length (mm): 4.8
Fish length (cm): 21.3
Fish weight (g): 345.0

Regression equations:
Length: SL = 4.89 (OL) – 0.29 r^2 **= 0.835**
Weight: WT = 0.0853 $SL^{2.664}$ r^2 **= 0.967**

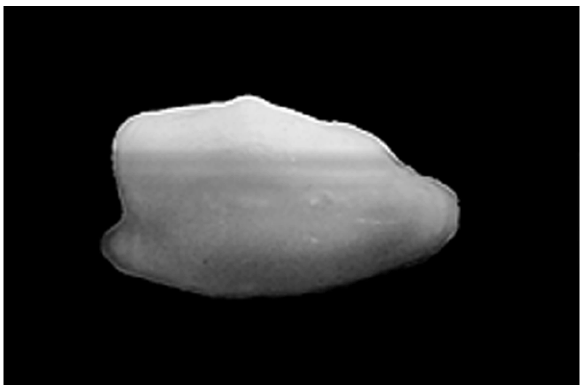
PLEURONECTIDAE (cont.)



Hypsopsetta guttulata
(diamond turbot)

Right otolith; length (mm): 4.7
Fish length (cm): 21.3
Fish weight (g): 345.0

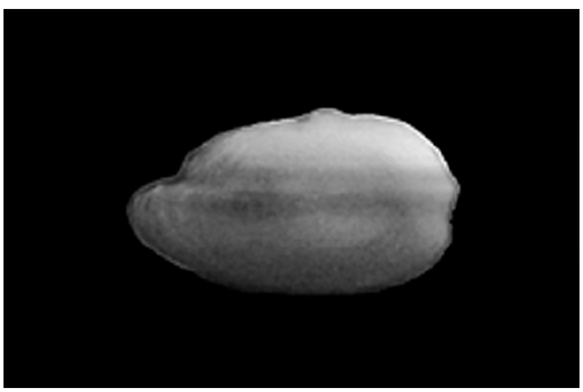
Regression equations:
Length: SL = 4.89 (OL) – 0.29 r^2 **= 0.835**
Weight: WT = 0.0853 $SL^{2.664}$ r^2 **= 0.967**



Microstomus pacificus
(Dover sole)

Left otolith; length (mm): 5.3
Fish length (cm): 26.9
Fish weight (g): 268.1

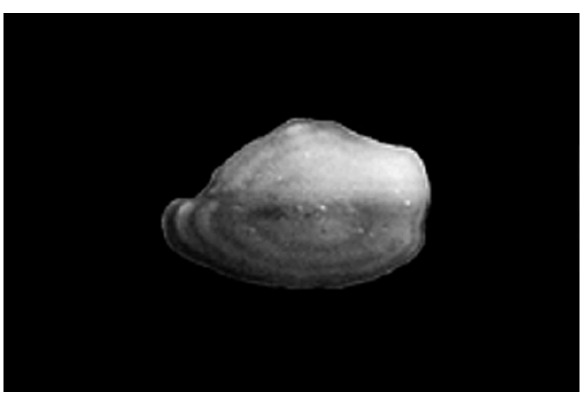
Regression equations:
Length: SL = 3.72 (OL) + 6.97 r^2 **= 0.587**
Weight: WT = 0.0094 $SL^{3.092}$ r^2 **= 0.854**



Microstomus pacificus
(Dover sole)

Right otolith; length (mm): 5.4
Fish length (cm): 26.9
Fish weight (g): 268.1

Regression equations:
Length: SL = 3.72 (OL) + 6.97 r^2 **= 0.587**
Weight: WT = 0.0094 $SL^{3.092}$ r^2 **= 0.854**

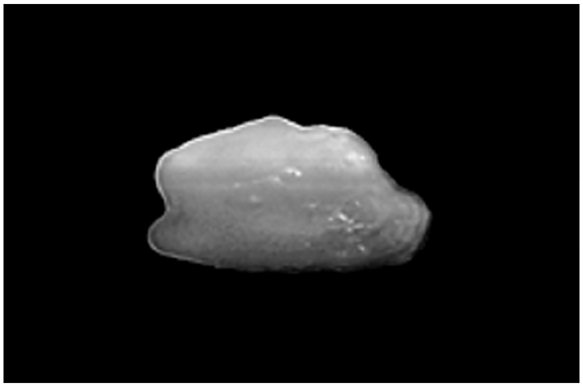


Microstomus pacificus
(Dover sole)

Right otolith; length (mm): 4.6
Fish length (cm): 26.2
Fish weight (g): 239.5

Regression equations:
Length: SL = 3.72 (OL) + 6.97 r^2 **= 0.587**
Weight: WT = 0.0094 $SL^{3.092}$ r^2 **= 0.854**

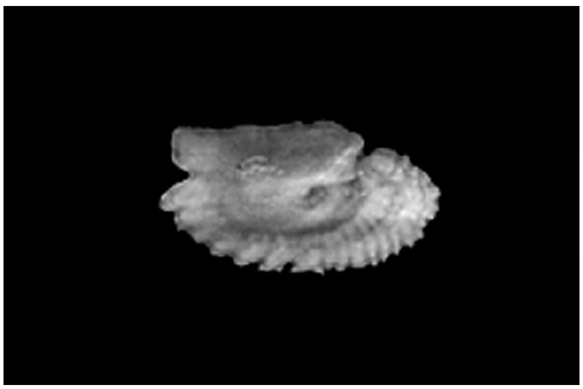
PLEURONECTIDAE (cont.)



Microstomus pacificus
(Dover sole)

Left otolith; length (mm): 4.8
Fish length (cm): 26.7
Fish weight (g): 289.0

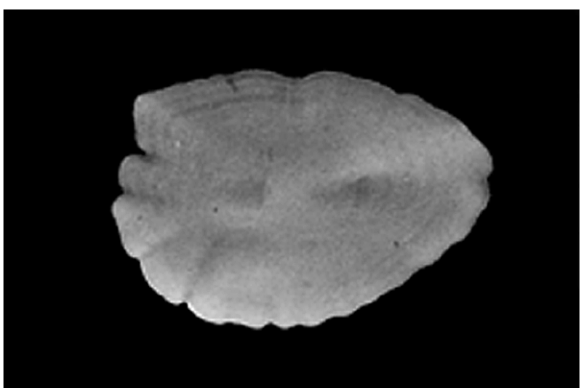
Regression equations:
Length: SL = 3.72 (OL) + 6.97 **r^2 = 0.587**
Weight: WT = 0.0094 $SL^{3.092}$ **r^2 = 0.854**



Platichthys stellatus
(starry flounder)

Left otolith; length (mm): 7.0
Fish length (cm): 27.6
Fish weight (g): 547.4

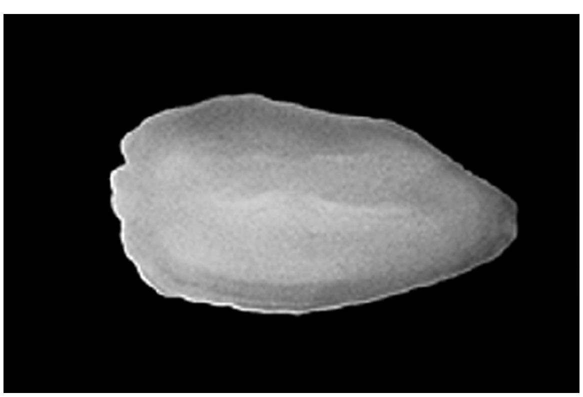
Regression equations:
Length: SL = 3.35 (OL) + 0.23 **r^2 = 0.814**
Weight: WT = 0.0107 $SL^{3.268}$ **r^2 = 0.985**



Pleuronectes asper
(yellowfin sole)

Left otolith; length (mm): 6.6
Fish length (cm): 25.3
Fish weight (g): 294.4

Regression equations:
Length: SL = 2.17 (OL) + 10.65 **r^2 = 0.638**
Weight: WT = 0.0024 $SL^{3.605}$ **r^2 = 0.859**

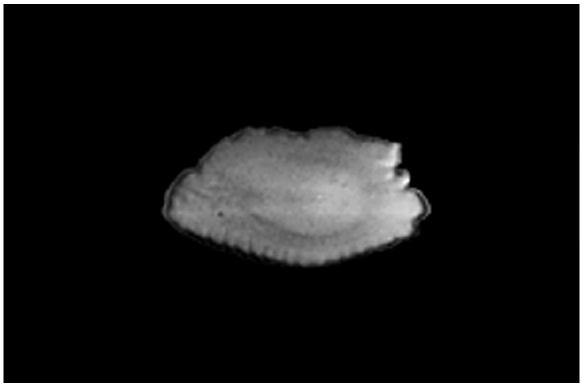


Pleuronectes bilineatus
(rock sole)

Left otolith; length (mm): 6.8
Fish length (cm): 23.5
Fish weight (g): 287.2

Regression equations:
Length: FL = 6.16 (OL) – 6.97 **r^2 = 0.841**
Weight: WT = 0.0112 $FL^{2.997}$ **r^2 = 0.931**

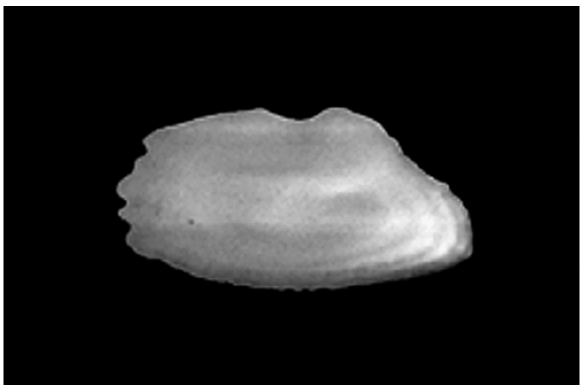
PLEURONECTIDAE (cont.)



Pleuronectes vetulus
(English sole)

Right otolith; length (mm): 6.6
Fish length (cm): 21.2
Fish weight (g): 104.0

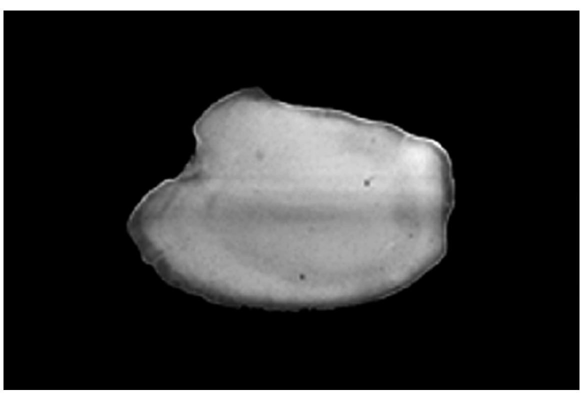
Regression equations:
Length: SL = 3.82 (OL) – 2.76 **r^2 = 0.965**
Weight: WT = 0.0163 $SL^{2.939}$ **r^2 = 0.995**



Pleuronectes vetulus
(English sole)

Left otolith; length (mm): 9.0
Fish length (cm): 32.3
Fish weight (g): 439.2

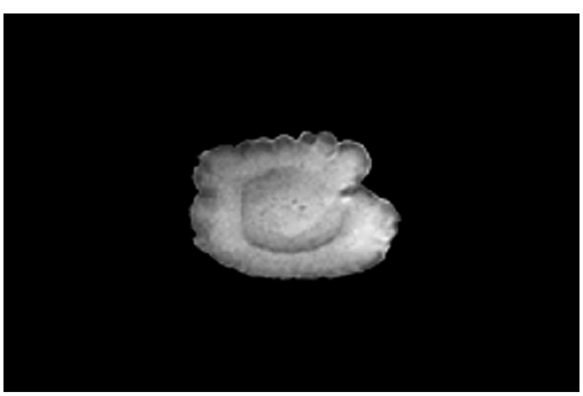
Regression equations:
Length: SL = 3.82 (OL) – 2.76 **r^2 = 0.965**
Weight: WT = 0.0163 $SL^{2.939}$ **r^2 = 0.995**



Psettichthys melanostictus
(sand sole)

Right otolith; length (mm): 5.2
Fish length (cm): 23.0
Fish weight (g): 288.0

Regression equations:
Length: SL = 5.06 (OL) – 3.18 **r^2 = 0.942**
Weight: WT = 0.0052 $SL^{3.441}$ **r^2 = 0.983**



Psettichthys melanostictus
(sand sole)

Left otolith; length (mm): 4.5
Fish length (cm): 21.7
Fish weight (g): 231.3

Regression equations:
Length: SL = 5.06 (OL) – 3.18 **r^2 = 0.942**
Weight: WT = 0.0052 $SL^{3.441}$ **r^2 = 0.983**

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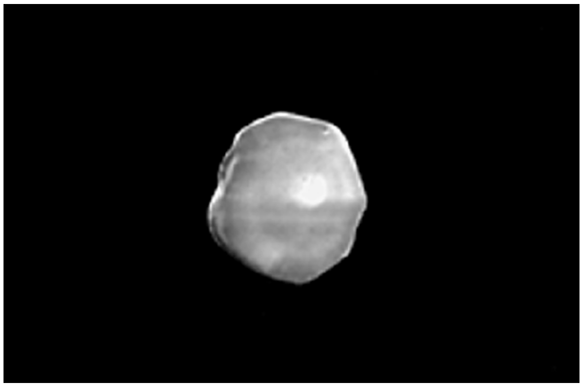

Symphurus atricauda
(California tonguefish)

Left otolith; length (mm): 2.3
Fish length (cm): 14.5
Fish weight (g): 33.2

Regression equations:

Length: **SL = 3.56 (OL) + 4.64** $r^2 = 0.464$
Weight: **WT = $0.0074SL^{3.136}$** $r^2 = 0.789$