■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Table 3 Combined salvage of delta smelt at the South Delta Export Facilities since the 1995 USFWS Biological Opinion.

Year and Water Year Type	*1995 (AN[a])*	*1996 (AN)*	*1997 (AN)*	*1998 (AN)*	*1999 (AN)*	*2000 (AN)*	*2001 (BN[b])*	*2002 (BN)*	*2003 (BN)*	*Reconsultation Level*	
FMWT (year-1)	899	127	303	420	864	756	603	139	210	Below Normal	Above Normal
December	54	0	18	281	16	126	192	1,129	2,800	8,052	733
January	2,057	4,189	0	130	28	802	181	5,231	9,561	13,354	5,379
February	481	1,290	1,730	24	1,466	7,831	3,870	280	1,494	10,910	7,188
March	16	155	1,159	592	564	2,746	3,772	225	483	5,386	6,979
April	24	111	32,828	48	410	1,746	520	372	504	12,354	2,378
May	0	30,399	7,876	4	58,929	49,500	13,170	47,361	16,324	55,277	9,769
June	0	9,441	228	66	73,368	50,490	2,418	11,926	10,156	47,245	10,709
WY Total	2,632	45,733	43,931	1,269	154,651	70,216	24,466	66,548	41,334		

[a] Above-normal year as defined by the USFWS 1995 Biological Opinion on the effects of long-term operation of the Central Valley Project and State Water Project (USFWS 1995)

[b] Below-normal year (USFWS 1995)

Length-Weight Relationships for 18 Fish Species Common to the San Francisco Estuary

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Introduction

Historically, the Department of Fish and Game (DFG) has used abundance indices (a relative index that reflects the numbers of fish) from the Summer Townet Survey (TNS), Fall Midwater Trawl Survey (FMWT), and the San Francisco Bay Study (SFBS) to track the trends in abundance of various species in the San Francisco Estuary. Abundance indices are easy to calculate and can provide insight into the relationship between young fish abundance and important environmental variables, such as outflow (see Turner and Chadwick 1972 for an example with striped bass [*Morone saxatilis*], Stevens and Miller 1983 for examples with Chinook salmon [*Onchorhynchus tshawytscha*], American shad [*Alosa sapidissima*], longfin smelt [*Spirinchus thaleichthys*], and delta smelt [*Hypomesus transpacificus*]).

Despite their long usage, abundance indices have one drawback: each fish caught is treated as 1 unit regardless of size (length) or condition (the "well being" of a fish, Anderson and Neumann 1996). The relationship between fish length (routinely collected) and mass (traditionally referred to as weight in fisheries science) is nonlinear (Anderson and Neumann 1996). Abundance indices do not take this nonlinear aspect into account. Therefore, there may be biological relationships that abundance indices are incapable of revealing or explaining. The weight of a fish can be used to calculate two different indices: biomass and condition.

Biomass indices are another relative index reflecting the mass of a collection of fish (such as a year class) rather than numbers (as with abundance indices). Biomass indices can take into account the nonlinear nature of mass and, when used for trend analysis, could reveal relationships with important environmental variables (such as outflow, see above) that may not be detected using abundance indices.

Condition indices give an indication of the overall condition or "fatness" (or as Anderson and Neumann 1996 put it, "well being") of an individual fish, rather than a group of fishes. Condition indices are determined by dividing the actual weight of a fish by some reference weight (Anderson and Neumann 1996) for a given length. Therefore it is possible to determine the average condition index for a given year class or a subset of a year class, based on region for example. The mean condition index could then be related to environmental variables, such as prey density, to help deter-

Table 1 Species collected for the Length-Weight Study (LWS) and minimum, mean, and maximum holding times (April-December 2003).

Species	Scientific name	Minimum	Holding time (days) mean (n)	Maximum
Speckled sanddab	(*Citharichthys stigmaeus*)	1	2.2 (220)	4
English sole	(*Pleuronectes vetulus*)	1	2.1 (178)	4
Plainfin midshipman	(*Porichthys notatus*)	1	1.7 (165)	4
Shiner surfperch	(*Cymatogaster aggregata*)	1	2.3 (162)	7
Northern anchovy	(*Engraulis mordax*)	1	1.8 (326)	4
Pacific herring	(*Clupea pallasi*)	1	1.4 (259)	6
Pacific sardine	(*Sardinops sagax*)	1	1.0 (39)	1
American shad	(*Alosa sapadissima*)	1	3.3 (429)	7
Bay goby	(*Lepidogobius lepidus*)	1	1.7 (202)	5
Yellowfin goby	(*Acanthogobius flavimanus*)	1	1.4 (171)	6
Staghorn sculpin	(*Leptocottus armatus*)	0	2.2 (132)	7
Topsmelt	(*Atherinops affinis*)	1	1.8 (248)	5
Jacksmelt	(*Atherinop californiensis*)	1	2.2 (75)	5
Striped bass	(*Morone saxatilis*)	0	1.4 (288)	4
Threadfin shad	(*Dorosoma petenense*)	1	2.2 (210)	8
Longfin smelt	(*Spirinchus thaleichthys*)	0	2.3 (295)	7
Delta smelt	(*Hypomesus transpacificus*)	1	2.3 (179)	7
Cheekspot goby	(*Ilypnus gilberti*)	2	2.0 (24)	2
Species with only 1 specimen collected—excluded from analysis				
Starry flounder	(*Platichthys stellatus*)	Processed 6 days after capture		
California grunion	(*Leuresthes tenuis*)	Processed 4 days after capture		
Brown smoothhound	(*Mustelus henlei*)	Processed 3 days after capture		

Results

Specimen collection began in April 2003 and ended in December 2003. Fishes were collected during the TNS, FMWT, SFBS, and the USFWS Beach Seine surveys (it was necessary to collect some topsmelt [*Atherinops affinis*] from inshore areas), with a total of 21 species being represented (Table 1). A large range of sizes, depending upon species, was also represented (Table 2). In all, 3,647 specimens were collected. There were 3 species where only 1 specimen was collected (Tables 1 and 2). These species were excluded from further analysis, resulting in 18 species with LWRs.

The goal of processing fish within ≤ 2 days of capture was not strictly met. Mean holding times ranged from 1 to 3.3 days (Table 1). Fish were held from 0 to 8 days after capture (Table 1). However, the majority of mean holding times were roughly 2 days (Table 1). After about one week, a noticeable odor of rotting fish was detected in the refrigerator.

Although all LWRs were significant (F test, $p < 0.0001$, Figures 1-18), the majority of relationships (14 out of 18) are considered to be incomplete[1] as the full size range for these species had not been adequately covered. For some fall or winter species, this was due to the late start (April 2003) of the LWS. The areas where more data are necessary are primarily at the lower and upper limits (ends) of the length range for the species requiring more observations (Table 3). Plainfin midshipman (*Porichthys notalus*) was the only species with a gap in the "middle" of the length-weight data where more data were deemed necessary (between 89 and

1. Gartz (2003) stated that the collection of specimens was complete for bay goby. Further analysis by the LWS, after the article was submitted, has indicated that more specimens are needed.

151 mm [TL]). The LWS will collect these additional specimens as resources allow. The LWRs that are the least complete are for Pacific sardine (Figure 1) and cheekspot goby (Figure 2).

Variability increased with length for almost all relationships with few outliers (Figures 1-18). Only one gross outlier was identified for northern anchovy (111 mm [FL], 19.9342 g, Figure 3). However, given the large number of observations and the position of the outlier (in relation to length) the LWS staff considered it of little consequence on the LWR for northern anchovy.

Table 2 Minimum and maximum weight (reported to the nearest milligram) and length (measured to the nearest millimeter) measurements of species collected for the Department of Fish and Game's Length-Weight Study (April-December 2003).

	Weight (gm)		*Standard*		*Fork length (mm)*		*Total*	
Species	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
American shad	0.547	61.943	34	162	37	172	41	202
Bay goby	0.070	6.420	22	78	N/A		26	93
Cheek goby	0.209	1.023	26	43	N/A		31	52
Delta smelt	0.065	7.230	21	86	23	94	24	102
English sole	0.205	39.478	24	138	N/A		28	165
Jacksmelt	0.908	359.700	43	298	48	326	51	350
Longfin smelt	0.055	18.412	20	114	22	122	23	132
Northern anchovy	1.010	32.620	47	141	53	148	57	163
Pacific herring	0.185	9.526	28	90	31	97	32	107
Pacific sardine	3.304	5.618	67	78	72	85	78	94
Pacific staghorn sculpin	1.956	114.785	47	178	N/A		56	209
Plainfin midshipman	0.126	105.670	18	206	N/A		20	227
Shiner surfperch	0.742	36.543	32	112	37	123	39	133
Speckled sanddab	0.410	24.945	30	115	N/A		36	137
Striped bass	0.040	41.973	14	131	15	148	16	158
Threadfin shad	0.201	41.666	25	128	28	135	30	157
Topsmelt	0.032	54.050	21	177	24	188	25	204
Yellowfin goby	0.051	49.249	16	154	N/A		19	187
Species where only 1 specimen was collected:								
Brown smoothhound[1]	96.015		293		N/A		N/A	
California grunion	5.397		80		88		95	
Starry flounder	6.510		66		N/A		77	

[1] The brown smoothhound was collected for an out-of-state organization that requested only standard length

Table 3 Species needing additional data at the lower and upper limits of the length range and the sizes needed for the LWS as of December 2003.

Species	*Less than*	*Greater than*
Topsmelt	76	154
Speckled sanddab	36	
Shiner surfperch	36	109
Staghorn sculpin	74	154
Pacific sardine	74	84
Pacific herring	39	84
Northern anchovy	56	124
Jacksmelt	56	154
English sole	36	
Cheekspot goby	36	
Bay goby	31	89
American shad		109
Delta smelt		64

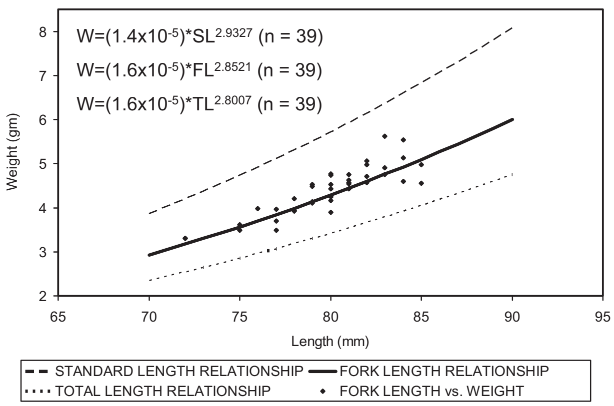

Figure 1 Length (mm)-weight (g) relationships for Pacific sardine with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 70-90 mm.

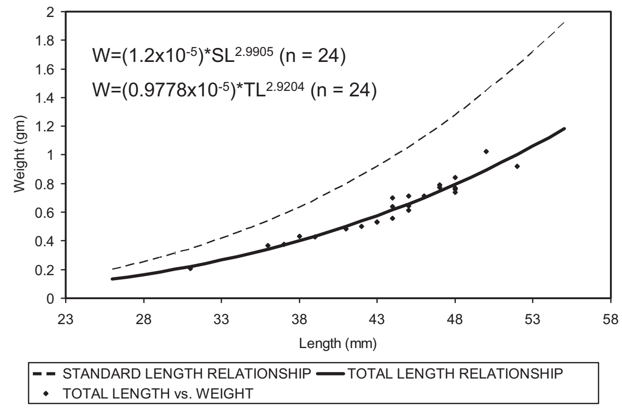

Figure 2 Length (mm)-weight (g) relationships for cheekspot goby with equations for standard length (SL) and total length (TL). Relationships are from 25-55 mm.

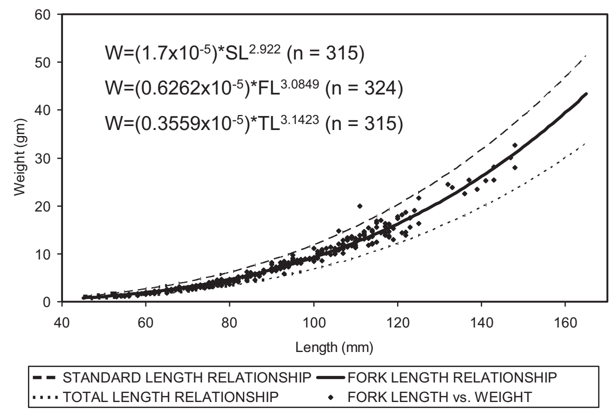

Figure 3 Length (mm)-weight (g) relationships for northern anchovy with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 45-165 mm.

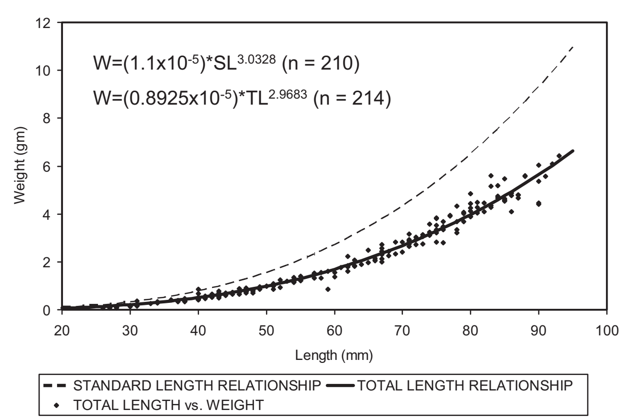

Figure 4 Length (mm)-weight (g) relationships for bay goby with equations for standard length (SL) and total length (TL). Relationships are from 20-95 mm.

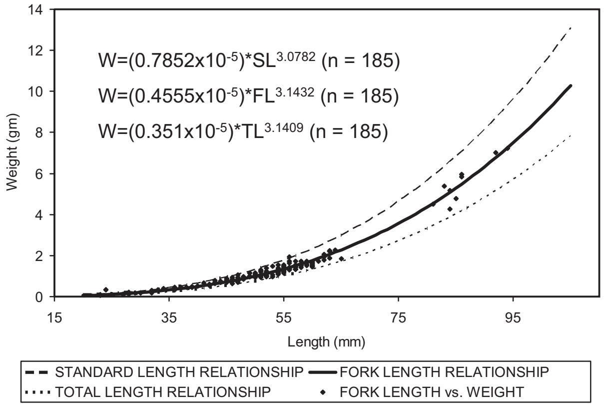

Figure 5 Length (mm)-weight (g) relationships for delta smelt with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 20-105 mm.

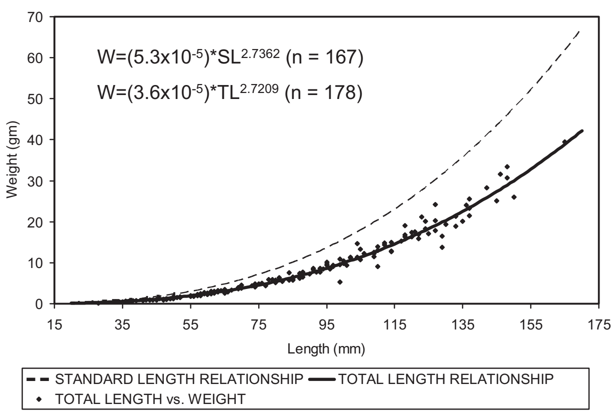

Figure 6 Length (mm)-weight (g) relationships for English sole with equations for standard length (SL) and total length (TL). Relationships are from 20-170 mm.

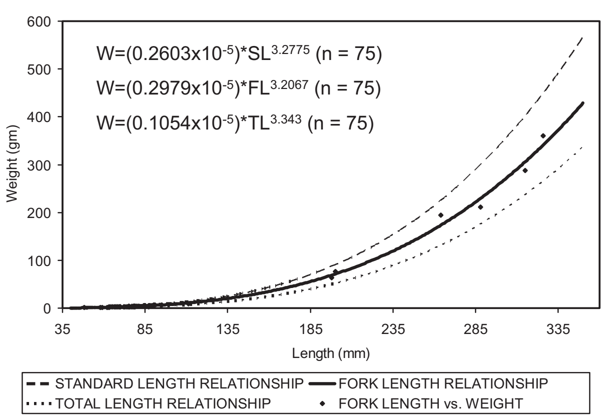

Figure 7 Length (mm)-weight (g) relationships for jacksmelt with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 40-350 mm.

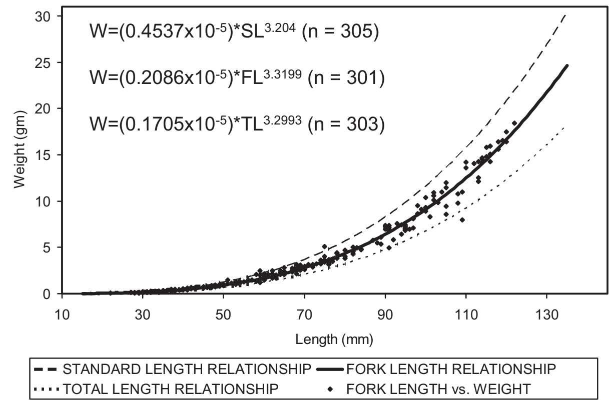

Figure 8 Length (mm)-weight (g) relationships for longfin smelt with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 15-135 mm.

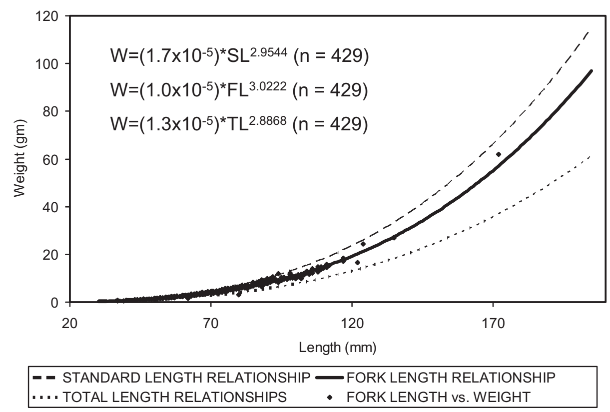

Figure 9 Length (mm)-weight (g) relationships for American shad with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 30-205 mm.

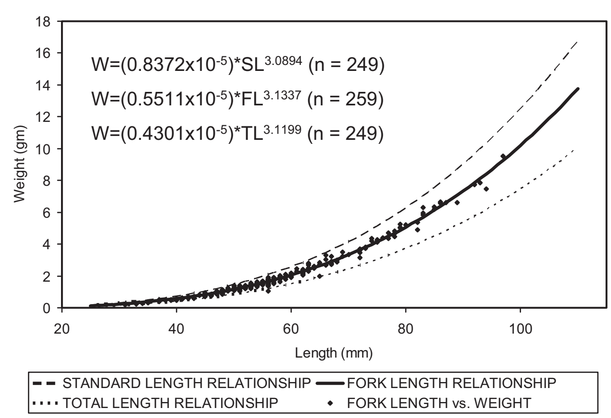

Figure 10 Length (mm)-weight (g) relationships for Pacific herring with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 25-110 mm.

mine what prevailing circumstances might enhance or detract from survival of a given species.

The first step in calculating either a biomass or condition index is to determine the length-weight relationships (LWR) for the species in question. In the absence of weighing all fish caught or extrapolating from a subsample, the LWRs for selected species are necessary to transform the length data that is routinely collected by the TNS, FMWT, and SFBS into weight for the calculation of a biomass index. To calculate a condition index, one or more LWRs are needed to determine a "reference weight" to compare with the actual weight of a fish to determine a condition index (Anderson and Neumann 1996). Depending upon the technique used to develop the reference weight, a single LWR is needed (Le Cren 1951) or multiple LWRs from the same species are needed (Murphy, Brown, and Springer 1990).

The goal of long-term monitoring activities by DFG's Central Valley Bay-Delta Branch is to determine biomass and condition indices for routinely encountered species and life stages in the TNS, FMWT, and SFBS. To accomplish this, a Length-Weight Study (LWS) was started in 2003. The first part of this study is the determination of LWRs for species routinely caught by the TNS, FMWT, and SFBS. This report details the LWRs determined as of December 2003. The calculation and evaluation of biomass and condition indices is scheduled for the later part of 2004 and into 2005. Due to budget constraints, the evaluation of condition indices has been curtailed to one species (striped bass) instead of the original four (longfin smelt, delta smelt, and threadfin shad [*Dorosoma pentenese*]).

Methods

The intention of the LWS was to determine the weight of fish just after capture, therefore giving the most accurate representation. Ideally, this would have been accomplished by weighing the fish immediately after capture on the boat. However, the balance (Mettler-Toledo AG-204) needed for the LWS would not function properly due to the motion of the boat. Therefore, the LWS preserved specimens in isotonic salt solution (roughly 12 ppt) and on ice. Isotonic salt solution was chosen to minimize water gain or loss through osmosis. Specimens were returned to DFG in Stockton and refrigerated on beds of ice to extend the time before they began to rot. They were not frozen because the effects of freezing could not be accounted for. Other data collected were: the date, time, and location of capture; the survey; and the gear used.

Processing consisted of weighing and measuring specimens. All fish were weighed to the nearest 0.1 mg if possible. For specimens that exceeded the limits of the balance (200 g) another balance was used and fish were weighed to the nearest gram. Fish that had ruptured (that is, the guts had burst or extruded through the abdominal wall) were excluded from processing. Fish that were bleeding slightly (mainly from the gills or eyes) were included. All fish were measured (standard length, total length, and, where applicable, fork length) to the nearest millimeter using a measuring board similar to those used in the field. For specimens that exceeded the limits of the measuring board (180 mm), a tape measure was used. This occurred for 14 specimens or 0.4% of all specimens collected between April and December 2003. The LWS definition of standard length is "from the most anterior part of the fish to the most posterior point where the body ends and the caudal fin rays begin". This definition was necessary as finding the hypural plate (Anderson and Neumann 1996) on small fish was difficult.

The goal for the time between capture and processing (holding time) was set at ≤ 2 days. This relatively quick "turnaround time" was determined necessary to process specimens before they rotted. The time between capture and processing (processing time) was determined by subtracting the Julian date when a fish was captured from the Julian date that a fish was processed. The minimum, maximum, and mean processing times were determined. Some processing times were omitted from the analysis due to recording errors. This resulted in 42 observations or 1.2% of all observations omitted from this analysis.

Species specific length-weight relationships were determined using the following formula (Anderson and Neumann 1996):

$$\text{WEIGHT} = a*\text{LENGTH}^b$$

This approach was chosen because it displays LWRs in their actual (non-transformed) form vice the log transformation (Anderson and Neumann 1996). Analysis was conducted using PROC NLIN (nonlinear regression) in SAS (SAS Institute, Inc. 1989). Species-specific LWRs were determined for all length measurements taken. Weight variability in relation to length was evaluated, by inspection, using either fork length or total length, as appropriate.

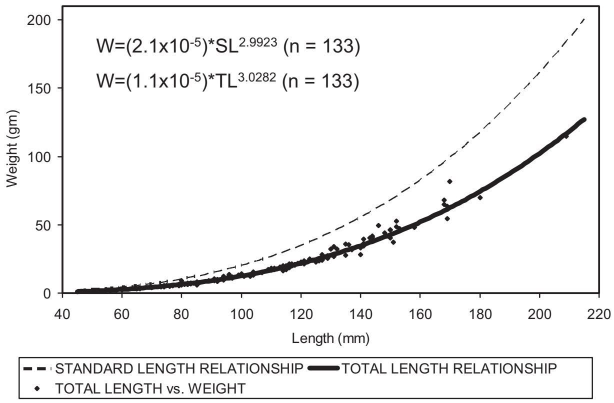

Figure 11 Length (mm)-weight (g) relationships for Pacific staghorn sculpin with equations for standard length (SL) and total length (TL). Relationships are from 45-215 mm.

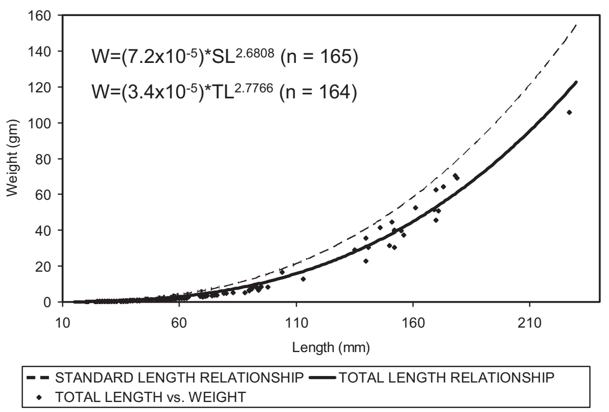

Figure 12 Length (mm)-weight (g) relationships for plainfin midshipman with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 15-230 mm.

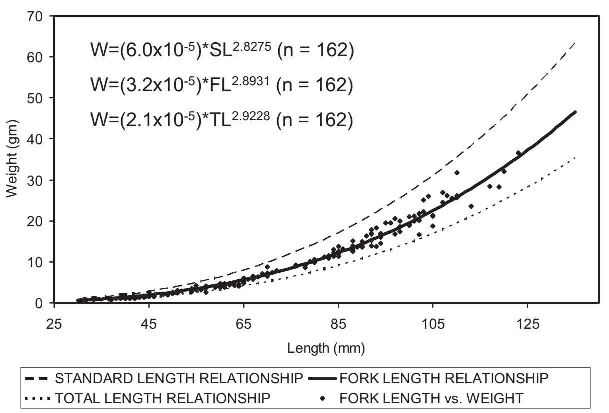

Figure 13 Length (mm)-weight (g) relationships for shiner surfperch with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 30-135 mm.

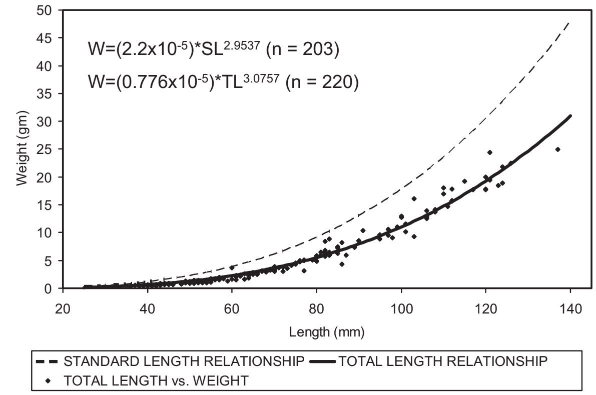

Figure 14 Length (mm)-weight (g) relationships for speckled sanddab with equations for standard length (SL), and total length (TL). Relationships are from 25-140 mm.

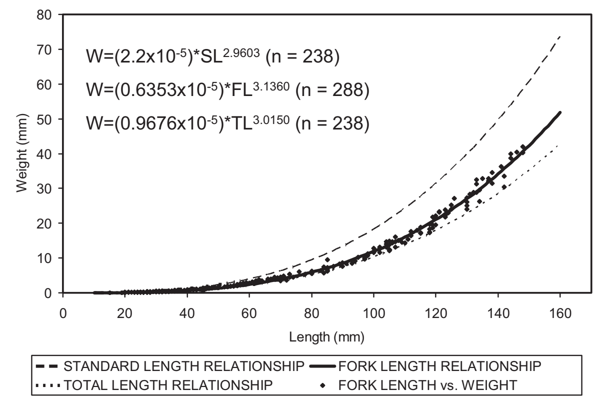

Figure 15 Length (mm)-weight (g) relationships for striped bass with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 10-160 mm.

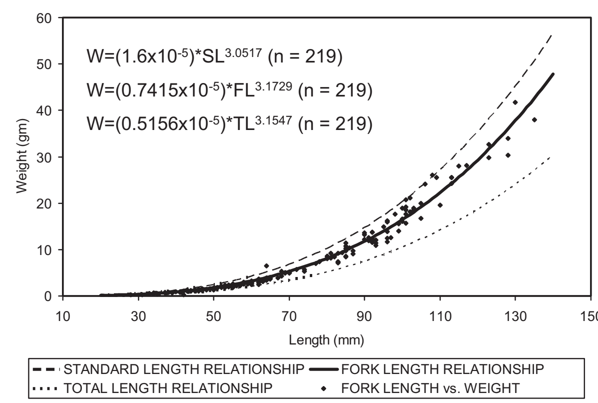

Figure 16 Length (mm)-weight (g) relationships for threadfin shad with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 20-140 mm.

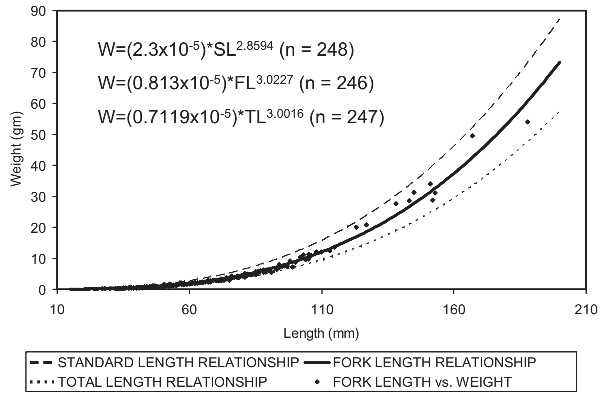

Figure 17 Length (mm)-weight (g) relationships for topsmelt with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 15-210 mm.

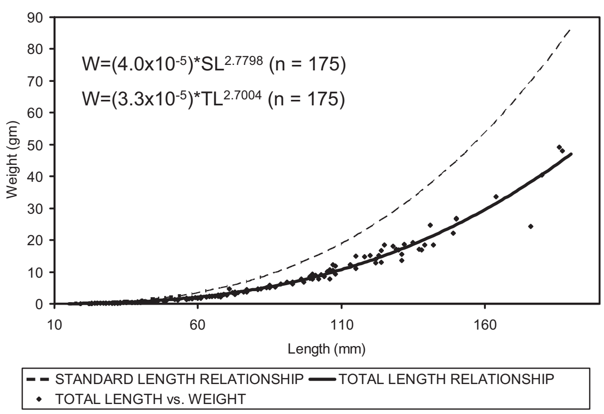

Figure 18 Length (mm)-weight (g) relationships for yellowfin goby with equations for standard length (SL), fork length (FL), and total length (TL). Relationships are from 10-190 mm.

Discussion

Despite the number of specimens already collected, the LWS has not collected length-weight data from the full range of sizes routinely encountered in a year, with the exception of 4 species (striped bass, threadfin shad, yellowfin goby, and longfin smelt). Therefore, the LWS data set is insufficient for determining the majority of LWRs and biomass indices. The LWS is collecting additional specimens of selected species in selected lengths to complete these data ranges (Table 3).

The LWS has yet to do an evaluation to determine if sufficient data have been collected to calculate useful condition indices. The LWR provides the reference weight for condition indices in a manner similar to Le Cren (1951). The LWS envisions that the condition index will take the form of weight of an individual fish divided by the LWR for a given species and length. Condition indices are used as response variables to help explain growth, mortality, and other processes. To accomplish this, sampling for the LWRs for condition indices must include fish that fully represent the length-weight variation within any given year class. Ideally, condition indices would be calculated for multiple year classes to help explain interannual trends. The LWS had originally planned to do this for 4 species: striped bass, threadfin shad, longfin smelt, and delta smelt. However, budget constraints in summer 2003 prompted the LWS to focus all sampling efforts on completing LWRs for biomass indices. Data collection for condition indices is planned for one species, striped bass, and will involve assessing the best method for collecting and processing specimens and to determining the appropriate analysis for comparing condition indices.

Conclusion

The LWS has collected more than 3,000 specimens representing 21 species. Out of the 21 species, 18 have LWRs. Only 4 species have LWRs sufficient for calculating biomass indices. It is not known if existing LWRs and the sampling schemes are adequate to calculate condition indices. Work is under way to complete the remaining LWRs for biomass indices and to determine if meaningful condition indices can be calculated.

Acknowledgements

I would like express my thanks to: Marade Bryant of DFG's Midsummer Townet Survey, Kelly Souza of DFG's Fall Midwater Trawl Survey, and Tom Greiner, Steve Slater and Kathy Hieb of DFG's San Francisco Bay Study for collecting specimens. I would also like to thank the US Fish and Wildlife Service for allowing Length-Weight Study personnel to go along on beach seine surveys to collect specimens. And a special thanks to Dave Contreras and Caley Costello for processing the majority of the fish used in this study.

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IEP Newsletter Distribution Delays

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The winter and spring 2004 editions of the *IEP Newsletter* have been delayed because of multiple problems with the mailing list and mailroom procedures. A new procedure has been worked out to get delivery back on track for the summer edition and for future newsletters. Expect to see the summer edition of the IEP Newsletter in mid-October.

Electronic versions of the delayed newsletters, as well as past editions, are available online at http://iep.water.ca.gov/report/newsletter/

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IEP NEWSLETTER

The Interagency Ecological Program for the San Francisco Estuary
is a cooperative effort of the following agencies:

California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Environmental Protection Agency

National Marine Fisheries Service

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