Length-weight Relationships for 71 Reef and Bottomfish Species from Tutuila and Aunu'u, American Samoa

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Introduction

Length and weight are two fundamental metrics used in studying fishes and almost any other living organism. The allometric growth equation ($Weight = a * Length^b$) is typically used to define the algebraic relationship between increases in fish length and weight. Once developed, this formula can be used to estimate weight with respect to length, or vice versa. For example, in creel surveys conducted by the American Samoa Department of Marine and Wildlife Resources (DMWR), the catch is rarely weighed in the field. To limit the time requested of fishermen, fish and invertebrates are quickly measured (Oram et al., 2010a; Oram et al., 2010b), and an estimated weight is calculated later. When length measurements are entered into the computer, missing weights are estimated based on known allometric growth formulas, either derived locally (1st choice) or from the literature for other regions (2nd choice).

Very little information has been published in the scientific literature regarding length-weight relationships for marine species in American Samoa. Some information exists for large pelagic species from the more prominent longline and purse seine fisheries (e.g. Curran and Bigelow, 2016). American Samoa's smaller-scale fisheries are very diverse and important to its culture and economy, yet much less well known. This study analyzes length-weight data collected from small-scale fisheries on the islands of Tutuila and Aunu'u, American Samoa, and summarizes allometric growth relationships determined for 71 fish species (and one invertebrate) for which sufficient data were available.

Materials and Methods

Data Source

Data collected in American Samoa through the Pacific Islands Fisheries Science Center (PIFSC) Commercial Fisheries Bio-sampling (CFBS) Program were retrieved from a database maintained by the Western Pacific Fishery Information Network (WPacFIN). Bio-sampling data were collected by DMWR staff working with the CFBS from October 9, 2010, through September 26, 2015. Over this period, 2290 fishing trips were sampled. Trip breakdown by fishing method was 92.1% spearfishing (without scuba), 6.3% bottomfishing, 0.9% bottomfishing/trolling mixture, and 0.7% atule (hook and line used for catching bigeye scad). Most of the catch from these trips was identified to species, and fish-fork length in centimeters (cm) and weight in grams (g) were recorded for most specimens. For crustaceans, carapace width (crabs) or carapace length (lobsters) was used. Data were collected for 257,110 specimens, representing 282 species and/or major taxa. Generally, weight measurements were not made once sufficient amounts of paired length-weight data were collected. Paired length-weight measurements were collected for 99,780 specimens. Only paired length-weight measurements for organisms identified to species were included in the present analysis.

Data Manipulation

Paired length-weight measurements were analyzed by species using the statistical language R (R Core Team, 2015). Code used in a similar analysis of CFBS data from Guam (Kamikawa et al., 2015; Branch and Essington, 2014) to automatically remove apparent outliers and produce parameters of the length-weight regressions was replicated for the American Samoa CFBS data. A few more stringent requirements were applied to screen out species with insufficient data quality and range. The general methodology is described below, including the differences between this and the previous study.

For each species, paired length-weight measurements were fit to the model:

$$W = a * L^b$$

where W is the weight (g), L is the fork length (cm), and a and b are model parameters. To estimate the parameters via linear regression, a natural log transformation was applied, yielding:

$$\ln(W) = \ln(a) + b * \ln(L)$$

Linear regression of the logged weight onto the logged length measurements produced estimates of $\ln(a)$ and b. The value of a was then estimated as $e^{\ln(a)}$.

After running the initial regression for each species, outliers were identified in ln-ln space as those points at a distance greater than four residual standard error measurements away from the regression line. Outliers were removed and the remaining paired length-weight measurements were re-fit to the model.

Although the code produced length-weight regression parameters for all species, only species deemed to have sufficient data for a reliable regression are reported. This was determined, based on three criteria:

- There must be 100 or more paired length-weight measurements for each species. This limit was increased from 50 in the Guam study to ensure that sufficient data were available to compute a reliable regression.
- The coefficient of determination (r^2) of the linear regression must be greater than or equal to 0.9 ($r^2 \geq 90\%$). This limit was increased from 0.8, which was used previously for Guam.
- Length-weight data must cover at least 30% of the total length range for the species. The total length range was defined as being from zero to the maximum known length for a given species. This maximum was defined as whichever length was greater, the maximum value reported in FishBase (Froese and Pauly, 2016) or the maximum length found in American Samoa CFBS data.

Results

Seventy-one species had sufficient paired data for a reliable length-weight regression (Table 1). One of these species, *Panulirus penicillatus*, is an invertebrate (spiny lobster) and the others are fish. Of the fish species, none had length-weight regression data from American Samoa and 12 had no length-weight regression data from any location in FishBase (Froese and Pauly, 2016).

Table 2 provides length-weight regressions for nine additional species. These species did not meet all three criteria for inclusion but are still mentioned due to their importance in fisheries. This includes the two surgeonfishes that are the most abundant species in the bio-sampling data (*Acanthurus lineatus* and *Ctenochaetus striatus*). The other 7 species are amongst the 30 most abundant species, which together make up over 90% of the total catch sampled by the CFBS program. These 9 species could not be included in Table 1 for various reasons: 1) 1 *(Selar crumenophthalmus)*, because it did not meet the length range coverage criterion, 2) 7 species (see Table 2), because they did not meet the coefficient of determination criterion, and 3) another species *(Myripristis murdjan)*, because it did not meet either the length range or coefficient of determination criteria. Length-weight relationships for these nine species should be used with caution.

Discussion

Although reliable length-weight relationships were established for 71 species, 20 other species had more than 100 paired length-weight measurements but could not be included in Table 1 because they did not meet one of the other two criteria. Two major taxa stood out amongst the 20 species that were excluded from the analysis. The first group was invertebrates in general, which is not surprising given their variable morphology. The other group was fishes of the family Acanthuridae. The collection of such large amounts of length-weight data represents a significant amount of effort. For this reason, we will describe some of the issues, in hopes of improving future data-collection efforts.

While there was only one invertebrate with sufficiently reliable length-weight data to report, three other invertebrate species had at least 100 paired length-weight measurements, including one slipper lobster and two crabs. *Parribacus caledonicus*, *Carpillius maculatus*, and *Etisus dentatus* all had coefficient of determination values far too low to produce a reliable length-weight curve. The coefficient of determination values for these species ranged from 65–72%. There are several potential causes for this lack of precision. First, the length-weight model may not be appropriate for most invertebrates. This could be true if their body shape changes significantly over time, such as may be seen during molting of crustaceans (especially when linked to changes in juvenile versus adult stages, sexual maturity and/or dimorphism).
It is also possible that there were inconsistencies in how length was measured for these oddly shaped species. Fork length of fishes is rather straightforward, but invertebrates tend to require

the use of metrics that may not be as obvious to the layman. To overcome this issue in the future, additional training has been provided, along with illustrated definitions for the appropriate measurement standards for fishes and invertebrates. This retraining and reinforcement of prior training may produce higher quality length-weight data.

There were seven species in the family Acanthuridae for which the length-weight curves fit to the data did not meet all criteria for inclusion, although data for four of these are provided in Table 2. Six of these species were in the genus *Acanthurus* (*A. achilles*, *A. blochii*, *A. guttatus*, *A. lineatus*, *A. nigricans*, and *A. olivaceus*); and the seventh species was *Ctenochaetus striatus*. All seven species only had moderately reliable coefficient of determination values (from 80% to 88%), although they had met the minimum amount of data and length range criteria. There were still nine acanthurids that had reportable length-weight relationships, but it is worthy of note that such a large proportion of this family had a fairly low coefficient of determination values. This could be caused by misidentification for various reasons, as well as the potential existence of cryptic species. There could also be natural causes, such as high variability in individual growth rates for acanthurids or seasonal differences in spawning and maturation. Acanthurids are an important part of small-scale fisheries in American Samoa, so these questions may indicate a useful application of further research.

Acknowledgments

A debt of gratitude is owed to all of the fishers who participated in the PIFSC Commercial Fisheries Bio-sampling Program. Many of them lent a lot of physical support to this work. They carried fish all about, willingly let DMWR staff know when they were coming in from fishing, helped with the separation of species in the catch and became a true part of the research effort. Fa'afetai tele lava! Without you, none of these data could have been collected.

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Tables

Table 1. Length-weight relationships for 71 species from American Samoa CFBS data. Sample size (n), minimum and maximum lengths (L_{min}, L_{max}), minimum and maximum weights (W_{min}, W_{max}), allometric growth parameters (a, b), 95% confidence intervals for the two model parameters (interval for parameter a given by "low95a", "high95a" and for parameter b by "low95b", "high95b"), and the regression coefficient (r^2) are given. Superscripts are used to denote species that: [a] are fish and do not have existing length-weight relationship data in FishBase (Froese and Pauly, 2016) or [b] are invertebrates (therefore not in FishBase).

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
[a]*Acanthurus grammoptilus*	391	15.2	35.6	96	1197	0.0265	3.00	0.0223	0.0314	2.95	3.06	0.96
[a]*Acanthurus maculiceps*	313	15.1	28.6	96	684	0.0154	3.21	0.0125	0.0190	3.14	3.28	0.96
Acanthurus nigricauda	614	15.1	45.3	91	2736	0.0151	3.21	0.0128	0.0177	3.16	3.26	0.96
Acanthurus xanthopterus	991	15.5	47.0	105	2816	0.0459	2.83	0.0419	0.0501	2.81	2.86	0.98
Aphareus rutilans	173	24.6	85.0	251	7931	0.0395	2.73	0.0330	0.0472	2.68	2.78	0.99
Aprion virescens	952	22.9	73.4	181	6727	0.0157	2.99	0.0140	0.0175	2.96	3.02	0.98
Caesio caerulaurea	1101	16.7	45.4	98	1634	0.0423	2.77	0.0357	0.0501	2.72	2.83	0.90
Caesio teres	173	15.6	29.0	77	573	0.0189	3.05	0.0140	0.0256	2.96	3.15	0.96
Calotomus carolinus	717	19.1	44.5	140	2018	0.0213	3.02	0.0182	0.0250	2.97	3.07	0.96
Carangoides orthogrammus	127	19.1	46.7	118	2399	0.0116	3.17	0.0082	0.0165	3.07	3.28	0.97
Caranx lugubris	164	17.5	86.0	122	13607	0.0404	2.80	0.0316	0.0517	2.73	2.87	0.98
Cephalopholis argus	1178	15.5	41.0	71	1278	0.0206	2.96	0.0186	0.0227	2.93	2.99	0.97
Cetoscarus bicolor	149	18.5	49.7	130	2415	0.0184	3.04	0.0149	0.0226	2.98	3.10	0.99
Cheilinus trilobatus	153	17.0	31.2	100	633	0.0401	2.80	0.0280	0.0574	2.68	2.91	0.94
[a]*Chlorurus frontalis*	596	19.0	49.5	131	2818	0.0202	3.02	0.0184	0.0222	2.99	3.05	0.99
[a]*Chlorurus japanensis*	6887	17.0	46.2	98	2220	0.0171	3.08	0.0164	0.0178	3.07	3.10	0.97
Chlorurus microrhinos	756	20.4	59.9	179	5324	0.0173	3.08	0.0160	0.0187	3.05	3.10	0.99
Chlorurus spilurus	377	18.0	48.6	111	2738	0.0166	3.09	0.0142	0.0194	3.04	3.14	0.98

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
Crenimugil crenilabis	380	23.0	48.2	246	1660	0.0388	2.73	0.0290	0.0517	2.65	2.81	0.92
Epinephelus maculatus	234	25.0	47.0	235	1640	0.0298	2.82	0.0199	0.0445	2.71	2.93	0.91
Epinephelus melanostigma	2662	16.9	54.9	78	3794	0.0119	3.10	0.0109	0.0129	3.08	3.13	0.95
Epinephelus merra	137	14.8	36.5	49	1001	0.0089	3.18	0.0060	0.0133	3.06	3.31	0.95
Epinephelus spilotoceps	113	17.5	47.5	84	1543	0.0228	2.91	0.0177	0.0294	2.83	2.99	0.98
[a]*Epinephelus timorensis*	106	18.0	71.0	109	4539	0.0174	2.94	0.0119	0.0256	2.83	3.06	0.96
Etelis coruscans	106	22.8	89.5	206	14000	0.0322	2.81	0.0236	0.0438	2.73	2.89	0.98
Gnathodentex aureolineatus	262	15.0	42.3	88	2098	0.0265	2.96	0.0200	0.0351	2.87	3.06	0.94
Kyphosus cinerascens	679	16.2	53.0	95	3606	0.0324	2.92	0.0297	0.0354	2.90	2.95	0.99
Kyphosus vaigiensis	596	16.7	44.7	109	2194	0.0269	2.97	0.0242	0.0299	2.94	3.00	0.98
[a]*Lethrinus amboinensis*	236	21.4	52.6	169	2348	0.0196	2.95	0.0156	0.0246	2.89	3.01	0.97
Lethrinus harak	280	19.9	54.9	142	2916	0.0317	2.83	0.0258	0.0389	2.77	2.90	0.97
Lethrinus olivaceus	108	33.9	65.5	673	4509	0.0420	2.72	0.0284	0.0624	2.62	2.83	0.96
Lethrinus rubrioperculatus	2349	17.8	57.0	101	3095	0.0287	2.86	0.0269	0.0306	2.84	2.88	0.97
Lethrinus xanthochilus	2190	19.8	54.5	137	2802	0.0280	2.85	0.0258	0.0303	2.83	2.88	0.97
Lutjanus bohar	166	13.8	69.0	52	5315	0.0248	2.92	0.0210	0.0293	2.88	2.97	0.99
Lutjanus fulvus	495	12.2	36.6	37	817	0.0270	2.88	0.0230	0.0316	2.83	2.94	0.96
Lutjanus gibbus	2296	17.0	56.8	94	2836	0.0399	2.80	0.0369	0.0431	2.78	2.82	0.96
Lutjanus kasmira	461	17.3	35.0	92	728	0.0176	3.01	0.0135	0.0229	2.93	3.10	0.91
Lutjanus monostigma	239	20.2	49.0	141	1941	0.0266	2.86	0.0218	0.0326	2.80	2.91	0.97
Lutjanus rufolineatus	566	15.9	27.5	81	402	0.0218	2.94	0.0175	0.0272	2.87	3.02	0.92
Lutjanus timorensis	164	23.0	73.7	115	6677	0.0019	3.56	0.0012	0.0030	3.44	3.68	0.95
Macolor niger	104	16.7	51.4	90	3308	0.0131	3.12	0.0102	0.0169	3.05	3.19	0.99
Monotaxis grandoculis	674	16.5	46.0	108	2319	0.0314	2.93	0.0288	0.0342	2.91	2.96	0.99
Mulloidichthys vanicolensis	127	18.0	39.8	93	1117	0.0278	2.88	0.0181	0.0427	2.74	3.02	0.93
[a]*Myripristis adusta*	164	14.2	28.5	79	524	0.0263	2.99	0.0199	0.0348	2.90	3.09	0.96
Myripristis berndti	4239	11.1	27.2	41	364	0.0990	2.54	0.0918	0.1066	2.51	2.56	0.90

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
[a]*Naso brachycentron*	143	23.4	55.0	242	3372	0.0189	2.99	0.0142	0.0253	2.92	3.07	0.98
Naso caeruleacauda	157	16.0	40.0	84	1096	0.0313	2.82	0.0244	0.0400	2.75	2.90	0.97
Naso lituratus	8806	12.4	47.4	64	2286	0.0224	3.02	0.0212	0.0236	3.00	3.04	0.93
Naso unicornis	5069	16.4	55.0	96	3431	0.0329	2.85	0.0320	0.0338	2.84	2.86	0.99
[b]*Panulirus penicillatus*	3384	4.3	15.8	78	2098	2.6004	2.41	2.4877	2.7181	2.39	2.43	0.94
Parupeneus barberinus	117	16.2	38.0	76	1145	0.0139	3.08	0.0099	0.0195	2.97	3.19	0.97
[a]*Parupeneus bifasciatus*	1421	15.0	34.5	70	656	0.0149	3.13	0.0134	0.0166	3.09	3.16	0.96
Parupeneus heptacanthus	278	18.3	35.8	104	877	0.0156	3.07	0.0122	0.0200	2.99	3.14	0.96
Pristipomoides flavipinnis	262	21.0	56.5	143	3039	0.0249	2.90	0.0209	0.0297	2.85	2.95	0.98
Sargocentron spiniferum	692	12.7	36.0	46	1016	0.0307	2.91	0.0277	0.0339	2.88	2.94	0.98
Scarus altipinnis	226	21.6	48.0	206	2610	0.0230	2.99	0.0185	0.0285	2.93	3.05	0.98
[a]*Scarus forsteni*	166	21.4	46.6	201	1467	0.0541	2.73	0.0359	0.0816	2.61	2.85	0.93
Scarus frenatus	1781	16.2	44.5	95	1885	0.0136	3.14	0.0129	0.0145	3.12	3.16	0.99
Scarus globiceps	1264	15.5	33.9	76	859	0.0193	3.04	0.0172	0.0217	3.00	3.07	0.95
Scarus niger	811	17.9	44.4	119	2000	0.0148	3.13	0.0132	0.0166	3.09	3.16	0.98
Scarus oviceps	3995	17.0	44.5	95	2105	0.0127	3.18	0.0120	0.0134	3.16	3.19	0.97
Scarus psittacus	311	18.2	43.0	118	1798	0.0189	3.03	0.0149	0.0240	2.95	3.10	0.95
Scarus rubroviolaceus	4570	17.2	54.0	102	3960	0.0115	3.18	0.0111	0.0119	3.17	3.19	0.99
[a]*Scarus tricolor*	100	17.0	52.7	116	2932	0.0223	2.99	0.0168	0.0296	2.90	3.07	0.98
Siganus argenteus	685	15.4	31.9	58	736	0.0157	3.05	0.0136	0.0182	3.00	3.09	0.96
Siganus punctatus	261	17.8	37.2	80	1135	0.0039	3.53	0.0027	0.0058	3.41	3.65	0.93
[a]*Siganus vermiculatus*	131	17.5	44.3	85	2393	0.0043	3.48	0.0028	0.0064	3.35	3.61	0.95
Sphyraena forsteri	382	27.0	92.3	185	4085	0.0183	2.73	0.0138	0.0242	2.66	2.80	0.94
Variola albimarginata	965	16.9	43.6	123	1177	0.1131	2.44	0.0951	0.1345	2.39	2.50	0.90
Variola louti	365	17.5	50.5	90	2311	0.0135	3.08	0.0116	0.0157	3.04	3.13	0.98
Zebrasoma veliferum	151	14.6	29.0	100	501	0.0421	2.82	0.0270	0.0658	2.68	2.97	0.91

Table 2. Length-weight relationships for 9 additional species from American Samoa CFBS data. These species did not meet the requirements for inclusion in Table 1 but are included here for reference due to their importance to fisheries. Sample size (n), minimum and maximum lengths (L_{min}, L_{max}), minimum and maximum weights (W_{min}, W_{max}), model parameters (a, b), 95% confidence intervals for the two model parameters (interval for parameter a given by "low95a", "high95a" and for parameter b given by "low95b", "high95b"), and the coefficient of determination (r^2) are given. Superscripts are used to denote species that: [a] are fish and do not have existing length-weight relationship data in FishBase (Froese and Pauly, 2016).

Scientific name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95 a	high95 a	low95 b	high95 b	r^2
Acanthurus guttatus	1879	12.7	24.5	72	470	0.0848	2.69	0.0744	0.0966	2.64	2.74	0.87
Acanthurus lineatus	1987	12.2	25.5	62	432	0.0625	2.71	0.0550	0.0710	2.66	2.75	0.88
Acanthurus nigricans	3013	12.4	36.0	66	620	0.1466	2.47	0.1297	0.1657	2.43	2.51	0.81
Ctenochaetus striatus	428	13.4	25.2	70	437	0.0440	2.82	0.0328	0.0592	2.72	2.92	0.87
Myripristis amaena	2857	9.6	22.5	23	265	0.1491	2.39	0.1329	0.1673	2.35	2.43	0.82
Myripristis murdjan	1713	13.1	27.5	64	324	0.7169	1.83	0.6442	0.7978	1.79	1.87	0.84
[a]*Priacanthus blochii*	1633	14.3	36.1	81	403	0.5178	1.89	0.4572	0.5864	1.85	1.93	0.84
Sargocentron tiere	3011	10.5	25.0	25	428	0.0690	2.62	0.0615	0.0773	2.58	2.66	0.85
Selar crumenophthalmus	298	15.0	32.7	51	646	0.0067	3.30	0.0053	0.0084	3.22	3.38	0.96