Length-weight Relationships for 83 Reef and Bottomfish Species from the Commonwealth of the Northern Mariana Islands

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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 Commonwealth of the Northern Mariana Islands (CNMI) Division of Fish and Wildlife (DFW), 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 the CNMI (e.g., Graham, 1994; Ralston, 1988). This study analyzes length-weight data collected from two small-scale commercial fisheries from the CNMI: the night free-diving spear and bottomfish fisheries. This report summarizes allometric growth relationships for 83 fish species and two invertebrates for which sufficient data were available.

Materials and Methods

Data Source

Data collected in the CNMI 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). The data were collected from January 2011 through October 2016, under a PIFSC contract with Micronesian Environmental Services, a private contractor based in Saipan. Over this period, 2,826 fishing trips were sampled. About 93% of the trips fished the area around Saipan, but other fishing trips occurred along the Mariana Archipelago from Rota in the south to Pagan in the north. Almost 95% of the trips the gear/method was spearfishing without scuba. The entire commercial catch from these trips was identified to species, and fork-length measurements in centimeters (cm) were obtained for every fish while weight in grams (g) was recorded for most specimens. For lobsters, carapace length was measured from the front of the carapace in between the eyes to the rear carapace edge. Data were collected for 208,737 specimens representing 229 species and/or major taxa. Generally, weights of individual fish were not collected once a sufficient number of paired length-weight data (i.e., greater than 500) were collected. Paired length-weight measurements were collected for 79,660 specimens. Only paired length-weight measurements for organisms identified to species were included in the present analysis. When length and weight measurements were entered into the database, any measured weight values more than 40% off of the predicted weight value (as calculated from the measured length) were labeled as outliers (error introduced in either recording, measuring or data entry) and deleted.

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 CNMI CFBS data. A couple of more stringent requirements were applied in comparison to what has been done for Guam to screen out species with inadequate data quality. The general methodology is described below, including the differences between this and the Guam 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 model was re-fit to the remaining paired length-weight measurements.

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 two criteria:

- There must be a minimum of 100 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 an accurate 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.

The Guam study using the CFBS data also excluded species with length data that covered less than 30% of the total length range. This criterion was not replicated in this study due to a lack of reliable local maximum length data for many of the species.

Results

Eighty-three species had sufficient paired data for a reliable length-weight regression (Table 1). Two of these species, *Panulirus penicillatus* (spiny lobster) and *Parribacus antarcticus* (slipper lobster), are invertebrates and the others are fish. Of the fish species, only 13 had prior length-weight regression data from the CNMI and 4 had no length-weight regression data from any location in FishBase (Froese and Pauly, 2016).

Discussion

Of the 83 species reported in Table 1, 15 could not be shown to have measured length ranges covering at least 30 percent of the total length range for that species. These 15 species included several of the most-caught species, such as *Acanthurus lineatus*, *Scarus ghobban*, *Lethrinus obsoletus*, and *Myripristis murdjan*. If the length coverage criterion from the past Guam CFBS data was implemented, none of these species would have been reported. For this reason, it is important to investigate why these species did not satisfy the length coverage criterion, and what limitations this may entail for the use of these species' results.

Maximum length values reported in FishBase (Froese and Pauly, 2016) for most of these 15 species were significantly larger than the maximum recorded length in the bio-sampling data. This caused the length range coverage to be less than 30%. However, the maximum lengths reported on FishBase can come from any geographic region within its global distribution, and fish of a given species on Saipan may not reach the same maximum length as they do elsewhere. Still, without Saipan-specific maximum length values, these species could not be shown to cover a sufficient portion of their length range.

The length-weight regression values reported in Table 1 should not be used outside of the length and weight range represented by the data. These ranges are given [L_{min}, L_{max}] and [W_{min}, W_{max}], respectively. Special attention should be given to those 15 species that may not have a large portion of their total length range covered. However, within the length and weight ranges represented by the data, length-weight relationships for all reported species should be reliable within Saipan, and to a lesser degree the entirety of the Northern Mariana Islands.

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Tables

Table 1. Length-weight relationships for 83 species from CNMI 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 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), [b] are invertebrates (therefore not in FishBase), [c] have existing length-weight relationship data for CNMI in FishBase (Froese and Pauly, 2016), or [d] did not have data to cover 30% of the total length range.

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
Sargocentron spiniferum	1029	13.1	36.5	56	1166	0.0280	2.94	0.0254	0.0309	2.90	2.97	0.97
Sargocentron tiere	1194	14.4	25.5	59	390	0.0316	2.89	0.0280	0.0356	2.85	2.93	0.94
Myripristis amaena	355	12.2	22.0	54	249	0.1351	2.41	0.1123	0.1626	2.35	2.48	0.94
Myripristis berndti	895	12.4	24.9	56	345	0.0653	2.68	0.0595	0.0717	2.65	2.71	0.97
[d]*Myripristis murdjan*	1210	12.3	22.3	56	255	0.1667	2.35	0.1517	0.1831	2.32	2.38	0.94
[d]*Myripristis violacea*	880	11.6	20.6	44	234	0.1297	2.45	0.1157	0.1455	2.41	2.50	0.94
Myripristis woodsi	117	14.4	23.5	80	366	0.0439	2.81	0.0304	0.0633	2.68	2.94	0.94
Cephalopholis argus	662	17.2	41.5	88	1534	0.0117	3.14	0.0105	0.0130	3.10	3.17	0.98
Epinephelus howlandi	421	17.4	46.1	86	1645	0.0085	3.20	0.0076	0.0094	3.17	3.24	0.99
Epinephelus merra	259	15.3	28.9	68	374	0.0222	2.89	0.0168	0.0294	2.80	2.98	0.94
Epinephelus polyphekadion	256	18.7	47.7	98	2236	0.0095	3.17	0.0080	0.0114	3.12	3.22	0.98
Epinephelus tauvina	318	19.1	50.8	104	2009	0.0077	3.20	0.0067	0.0089	3.16	3.25	0.99
Epinephelus macrospilos	141	18.4	42.5	96	1392	0.0088	3.20	0.0073	0.0107	3.14	3.25	0.99
[d]*Heteropriacanthus cruentatus*	721	17.2	28.2	80	342	0.0270	2.81	0.0235	0.0311	2.76	2.85	0.95
Carangoides orthogrammus	265	12.8	57.8	42	3926	0.0224	2.96	0.0201	0.0249	2.93	2.99	0.99
[c]*Caranx lugubris*	130	25.5	82.5	438	9394	0.0313	2.87	0.0251	0.0390	2.82	2.93	0.99

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
Caranx melampygus	215	10.2	56.8	20	3158	0.0216	2.96	0.0195	0.0239	2.93	2.99	0.99
[c,d]*Selar crumenophthalmus*	2963	13.2	28.6	32	413	0.0053	3.38	0.0051	0.0055	3.37	3.39	0.99
Carangoides ferdau	193	11.6	52.4	28	3138	0.0217	3.01	0.0193	0.0244	2.98	3.05	0.99
Mulloidichthys flavolineatus	2798	8.3	31.4	7	469	0.0138	3.05	0.0134	0.0142	3.04	3.06	0.99
Mulloidichthys vanicolensis	1026	10.4	28.0	15	438	0.0105	3.19	0.0098	0.0113	3.17	3.22	0.99
Parupeneus barberinus	2737	8.2	37.3	10	962	0.0175	3.01	0.0170	0.0181	3.00	3.02	0.99
[a]*Parupeneus insularis*	651	14.5	30.3	61	670	0.0100	3.27	0.0086	0.0117	3.22	3.32	0.96
Parupeneus cyclostomus	331	15.0	34.6	60	739	0.0152	3.07	0.0134	0.0173	3.03	3.11	0.99
Parupeneus ciliatus	1047	12.3	28.9	38	554	0.0150	3.12	0.0136	0.0166	3.08	3.15	0.97
Parupeneus multifasciatus	726	11.1	27.1	25	400	0.0166	3.07	0.0141	0.0196	3.01	3.13	0.94
[a]*Upeneus arge*	597	14.7	32.3	48	554	0.0119	3.11	0.0107	0.0132	3.07	3.14	0.98
Kyphosus cinerascens	915	15.5	44.4	84	2212	0.0235	3.01	0.0217	0.0254	2.99	3.04	0.99
Kyphosus vaigiensis	892	17.6	49.5	122	2878	0.0206	3.03	0.0186	0.0227	3.00	3.06	0.98
Crenimugil crenilabis	259	16.2	42.5	66	1190	0.0111	3.08	0.0093	0.0134	3.02	3.13	0.98
[d]*Cheilinus chlorourus*	115	16.4	25.0	90	298	0.0288	2.88	0.0188	0.0442	2.74	3.02	0.94
Cheilinus trilobatus	1477	15.5	35.2	82	782	0.0451	2.73	0.0418	0.0487	2.70	2.75	0.97
Cheilinus undulatus	377	16.5	125.5	88	34473	0.0162	3.04	0.0148	0.0176	3.02	3.07	0.99
Hemigymnus melapterus	399	17.7	39.6	90	1321	0.0210	2.96	0.0183	0.0241	2.92	3.01	0.98
Calotomus carolinus	1023	15.7	32.2	82	834	0.0131	3.16	0.0118	0.0147	3.12	3.19	0.97
[a]*Hipposcarus longiceps*	636	14.8	52.1	56	3101	0.0148	3.07	0.0141	0.0155	3.05	3.08	1.00
Leptoscarus vaigiensis	813	16.8	35.2	90	657	0.0184	2.94	0.0162	0.0208	2.90	2.98	0.97
Scarus altipinnis	839	17.0	51.5	104	3100	0.0173	3.05	0.0162	0.0184	3.03	3.07	0.99
[a]*Chlorurus frontalis*	669	15.7	49.3	77	2783	0.0137	3.13	0.0129	0.0146	3.12	3.15	0.99
[d]*Scarus ghobban*	1644	14.9	38.1	62	1228	0.0129	3.12	0.0122	0.0136	3.10	3.13	0.99
Chlorurus microrhinos	694	16.9	56.9	100	4025	0.0151	3.11	0.0142	0.0159	3.10	3.13	1.00
[d]*Scarus globiceps*	424	17.2	28.4	112	505	0.0174	3.06	0.0140	0.0218	2.99	3.13	0.94
Scarus psittacus	816	16.2	28.9	90	494	0.0211	2.99	0.0187	0.0240	2.95	3.03	0.96

Scientific Name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	b	low95a	high95a	low95b	high95b	r^2
Scarus rubroviolaceus	1830	17.7	52.6	112	3278	0.0089	3.24	0.0084	0.0093	3.23	3.26	0.99
Scarus schlegeli	498	18.1	33.5	118	748	0.0239	2.95	0.0203	0.0281	2.90	3.00	0.96
Chlorurus spilurus	1603	14.5	30.8	62	580	0.0171	3.09	0.0158	0.0184	3.06	3.11	0.97
Acanthurus guttatus	326	14	21.3	98	374	0.04011	2.955	0.03086	0.05212	2.8624	3.0469	0.92
[d]*Acanthurus lineatus*	4927	13.8	23.5	62	366	0.03882	2.868	0.03591	0.04197	2.8406	2.8943	0.9
Acanthurus blochii	826	14.2	38.7	74	1406	0.01838	3.115	0.01713	0.01972	3.0925	3.1376	0.99
Acanthurus nigricauda	890	13	26.3	60	558	0.02179	3.057	0.01956	0.02427	3.0213	3.0934	0.97
[d]*Acanthurus olivaceus*	119	15.4	24.5	80	396	0.02313	3.032	0.01496	0.03575	2.8839	3.1801	0.93
[d]*Acanthurus triostegus*	741	12	19.5	50	219	0.03671	2.911	0.03203	0.04206	2.8615	2.9602	0.95
Acanthurus xanthopterus	580	13.6	39.5	60	1492	0.02907	2.954	0.02709	0.0312	2.9315	2.9759	0.99
[d]*Ctenochaetus striatus*	229	13.8	21.4	70	390	0.02911	2.968	0.02017	0.04201	2.8391	3.0971	0.9
Naso lituratus	3868	14	30.1	56	546	0.01663	3.103	0.01548	0.01786	3.0795	3.1271	0.94
Naso unicornis	4448	15.9	53.6	84	2848	0.0269	2.908	0.02621	0.02762	2.9005	2.9161	0.99
Siganus argenteus	3961	10	34.1	16	774	0.0129	3.112	0.01254	0.01327	3.1022	3.121	0.99
Siganus punctatus	838	11.6	34.8	32	1114	0.01276	3.196	0.01181	0.01379	3.1699	3.2212	0.99
Siganus spinus	1674	10.2	26.6	18	404	0.0116	3.158	0.01102	0.01222	3.1396	3.1762	0.99
[b]*Panulirus penicillatus*	1221	5.6	17	156	2484	1.49499	2.692	1.42737	1.56582	2.6704	2.7126	0.98
[b]*Parribacus antarcticus*	933	4.4	9	40	368	0.6672	2.809	0.60746	0.73282	2.7608	2.8566	0.93