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Updated Weight-on-Length Relationships for Pelagic Fishes Caught in the Central North Pacific Ocean and Bottomfishes from the Northwestern Hawaiian Islands

James H. Uchiyama
Thomas K. Kazama

NOAA Fisheries
Pacific Islands Fisheries Science Center
Honolulu, Hawaii

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For further information direct inquiries to

Chief, Scientific Information Services
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
2570 Dole Street
Honolulu, Hawaii 96822-2396

Phone: 808-983-5386
Fax: 808-983-2902

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INTRODUCTION

Models of biomass dynamics used in fish stock assessment typically require the prediction of body weight from some measure of length. As the focus of fishery management broadens to include a wider range of species in marine ecosystems[1] there is a growing need to develop weight-on-length (WL) predictors not only for the main fish species caught but also for species caught incidentally. Using fish weight and length data collected during research cruises of the NOAA Ship *Townsend Cromwell* (*TC*) during the last 25 years, and other sources, we estimated WL relationships for 12 pelagic species caught in eastern and central North Pacific fisheries and 12 bottomfish species from the Northwestern Hawaiian Islands (NWHI). The species studied include:

<u>Pelagic species</u>

kawakawa--*Euthynnus affinis*
skipjack tuna--*Katsuwonus pelamis*
albacore--*Thunnus alalunga*
yellowfin tuna--*T. albacares*
bigeye tuna--*T. obesus*
sailfish--*Istiophorus platypterus*
black marlin--*Makaira indica*
Pacific blue marlin--*M. mazara*
shortbill spearfish--*Tetrapturus angustirostris*
striped marlin--*T. audax*
longnose lancetfish--*Alepisaurus ferox*
snake mackerel--*Gemplus serpens*

<u>Bottomfish species</u>

hapuʻu, *Epinephelus quernus*
butaguchi, *Pseudocaranx dentex*
kahala, *Seriola dumerili*
ehu, *Etelis carbunculus*
onaga, *E. coruscans*
taʻape, *Lutjanus kasmira*
ʻopakapaka, *Pristipomoides filamentosus*
kalekale, *P. sieboldii*
gindai, *P. zonatus*
blackspot wrasse, *Bodianus bilunulatus*
oʻopu kai nohu, *Pontinus macrocephalus*
purple snake mackerel, *Promethichthys prometheus*

A few of these species occur in the bycatch (discards) of commercial fisheries, and the predictors we present provide the first published WL relationships for them from this area. In the other cases, the predictors provide alternatives or updates to relationships already available in the literature. Publications of WL relationships of pelagic species in Hawaiian waters are limited. Relationships of commercially fished tunas (skipjack tuna,

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[1]National Marine Fisheries Service and Ecosystem Principles Advisory Panel. 1999. Ecosystem-based Fishery Management. A report to congress by the Ecosystem Principles Advisory Panel as mandated by the Sustainable Fisheries Act amendments to the Magnuson-Stevens Fishery Conservation and Management Act of 1996, NMFS, Washington, D.C. 54 p. Online at http://www.nmfs.gov/sfa/EPAPrpt.pdf

yellowfin tuna, bigeye tuna, and albacore) are available in a report by Nakamura and Uchiyama (1966). The relationships are based on thousands of fish measurements and cover the wide size range of these species, but error estimates are not provided. Weight-on-fork length (WFL) relationships are presented for seven billfishes (swordfish included) in the report by Skillman and Yong (1974) and in a later publication that provided functional (WFL) for the striped marlin and the Pacific blue marlin (Skillman and Yong, 1976). Skillman and Yong (1974, 1976) did not use eye-to-fork length (EFL), which most studies on Pacific billfishes use, and sample sizes for some species were very small. Wilson et al. (1991) provided weight-on-lower jaw fork length relationship for Pacific blue marlin collected primarily at Kona, Hawaii. Tester and Nakamura (1957) calculated WL relationships for several of the miscellaneous pelagic species such as kawakawa; mahimahi, *Coryphaena hippurus*; and wahoo, *Acanthocybium solandri*. Size ranges were limited to small fish, and no error estimates were provided. More recent studies on swordfish, *Xiphias gladius* (Uchiyama et al., 1999), and mahimahi and wahoo (in prep)[2] utilized extensive data collected at the Honolulu fish auction and on research cruises. The latter reports examined effect of sex and month on WL relationships and provided model and parameter error estimates for swordfish, mahimahi, and wahoo. Therefore, analyses for the latter species will not be duplicated here.

Publications on WL predictors of bottomfishes are also limited. Ralston presented a WL relationship for ʻopakapaka in his Ph.D. dissertation (1981). WL relationships of snappers, grouper, and jacks caught by handline in the NWHI on the NOAA ship *TC* during 1977-82 were presented at the Second Symposium on Resource Investigations in the NWHI in 1983 (Uchiyama et al., 1984). DeMartini and Lau (1999) presented (ovary-free body) WL relationships for ehu and kalekale in their study to find a more cost-effective way to determine sexual maturity. In the life history and ecology study of large jacks, Sudekum et al. (1991) provided equations for weight-on-standard length relationships as well as various length-length relationships to convert other length measurements to standard-length for white ulua, *Caranx ignobilis,* and ʻomilu, *C. melampygus,* from the NWHI. Sudekum et al. (1991) can be consulted for WL relationships of white ulua and ʻomilu and will not be repeated here.

In addition to estimating WL predictors, the effect of sex on the WL relationship was examined for species with adequate sample size. Separate relationships are presented for each sex when WL parameters differed significantly between sexes; in these cases, predictors for pooled sexes are also provided for use when sex is unknown. Both WL and length-on-weight (LW) relationships were characterized to provide a comprehensive reference source. Standard errors were provided for the predictor models and model parameters.

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[2]Uchiyama, J. H., and C. H. Boggs. In prep. Length weight relationships for mahimahi, *Coryphaena hippurus*, and wahoo, *Acanthocybium solandri*, landed at the Honolulu fish auction.

METHODS

Length, weight, and sex data were obtained for fish caught on research cruises on the ship *TC* from June 1977 through September 2002. Lengths were measured in millimeters using a meter or a 2-m-long fish caliper. Fish were measured for fork length (FL), except for billfishes where EFL was used and total length (TL) for certain demersal species that have rounded or truncated tails. From 1977 to 1992 whole weight up to 25 kg was usually measured on a Maco[3] beam platform balance scale. An electronic platform scale (Electronic Platform Scales FG60K (60 ±0.02 kg) replaced the Maco beam balance in 1992. Large fish were weighed using a steelyard prior to 1992; fish were weighed to the nearest whole pound. From 1992, an electronic crane scale (Challenger MSI-3260) with a capacity up to 225 (±0.1) kg was used for large fish and occasionally, a 25-kg or a 10-kg-capacity spring scale was used in the field. Honolulu Laboratory's data sets FISH SAMPLING LOG (RI003), STANDARDIZED TROLLING DATA (RP002), and SIZE FREQUENCY LOG (RI016) were our data sources. Only length-weight-sex data of pelagic species caught in the North Equatorial Current (NEC) (east of the international date line) and bottomfishes caught and surveyed in the NWHI and main Hawaiian Islands were extracted from the data base. All relationships were fitted using centimeters (cm) and kilograms (kg); therefore, pounds (steelyard and other data) and grams (old data format) were converted to kg and millimeters to cm. A multiplicative relation of WL was performed for all species, and observations with Studentized residual values of ≥ 3 were considered outliers and were not used in the WL characterization. These data appeared to consist of measurement or recording errors. An outlier limit of ≥ 3 Studentized residual is conservative; any of the species examined in this report, at peak condition with a fully developed gonad ready to spawn and with a full stomach, would not have deviated as much from the predicted mean size. All statistical analyses were performed using Statgraphics Plus Professional version 5 (Manugistics, 2000).

We supplemented our data for albacore and Pacific blue marlin from other sources to increase both number and size range. Length-weight data of smaller albacore were obtained from recaptured tagged fish from the eastern North Pacific Ocean including Hawaii and were added to our data to increase the size range. These small albacore had previously been frozen, thawed, and weighed on a triple beam scale on land; fork length was measured using a fish caliper.[4] Since only a single stock-unit of albacore tuna is believed to exist in the North Pacific (Nakano, 1996) and some of the small albacore tagged in the eastern North Pacific Ocean were recaptured in Hawaii, supplementing our

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[3]The National Marine Fisheries Service/NOAA Fisheries does not approve, recommend, or endorse any proprietary products or proprietary material mentioned in this report.

[4]Robert Nishimoto, Fishery Biologist, Honolulu Laboratory, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2570 Dole Street, Honolulu, Hawaii 96822-2396.

data with small albacore from the eastern North Pacific tag return records was considered reasonable. Our data for Pacific blue marlin were supplemented with published measurements of fish caught in the NEC east of the international date line (Royce, 1957). Since Pacific blue marlin appear to be concentrated at the Equator and its density diffuses to the north and south of the Equator (Honma and Kamimura, 1958; Nakamura, 1974), fish caught at the Equator were also included. Because morphometric differences have been reported for striped marlin caught in the northern and southern hemispheres of the Pacific Ocean (Kamimura and Honma, 1958; Wares and Sakagawa, 1974), only measurements of striped marlin caught in the NEC were used. Data collected on billfishes at Honolulu's two fish auction (Honolulu Laboratory data set AUCTION MARKET LONGLINE CATCH MEASUREMENTS (RP025)) were analyzed to supplement the WL relationships of billfishes based on small sample sizes collected on research cruises. Although fish lengths were rarely measured at the Honolulu fish auctions, billfishes were measured for EFL and sexed from 1967 to 1970. Auction weights were recorded; commercially landed billfishes lacked their bill when weighed.

The effect of sex on the log-linearized WL relationship was examined by multiple regression analyses for species with a sufficiently large number of measurements. An ANOVA table with the conditional sum of squares was used to determine the significance of each term in the model. WL relationships were calculated for all species with sexes pooled (males, females, and not sexed). When there was a significant difference between the relationships of males and females, relationships were also calculated separately by sex.

WL and LW relationships were calculated by finding a least-squares solution to a nonlinear regression. WL relationships were fitted to the data by the second order polynomial regression analysis. The constant and the middle term were usually not significant, so they were eliminated from the model, and the relationship ended with the familiar power function equation, $Y = aX^b$. However, the full polynomial equation did improve the WL fit for three relationships, and a fourth relationship required a third order polynomial equation.

RESULTS AND DISCUSSION

Effects of sex on log-linearized WL relationships were examined for only five species of tunas (Scombridae), six species of snappers (Lutjanidae), and two species of jacks (Carangidae, Table 1). No sexual dimorphism was detected for any of the tunas (Table 1). Significant differences in Y-intercepts between sexes were detected for four species: onaga, ‘opakapaka, gindai, and butaguchi (Table 1). The differences in Y-intercepts were highly significant ($P = 0.001$) for gindai, significant for butaguchi ($P = 0.03$), and marginally significant for ‘opakapaka ($P = 0.058$) and onaga (0.053). None of the other lutjanids and carangids examined were sexually dimorphic. WL and LW relationships were fitted to the data with sexes pooled for all species and separately for males and females for the four species that had significantly differences in Y-intercepts between sexes (Tables 2-3). Sexual dimorphism was not examined for the longnose lancetfish because it is hermaphroditic (Smith and Atz, 1973). Plots of whole WL relationships for the tunas, two species of billfishes, snappers, grouper, carangids, and miscellaneous (incidental and bycatch) species were prepared, displaying observed data and the fitted curve (Figs. 1-20).

The WL relationship for kawakawa collected in the NWHI is unique in that it was based on a large sample size of 600 measurements and covered a wide size range (27.8-79.9 cm fork length). A data collection like this would be difficult to obtain today because of an apparent decline in its population during the last two decades. The smaller fish lay below the curve (Fig. 13), so other curve fitting procedures were attempted, but without success. Small albacore lay above the fitted power function curve; by fitting the complete 2nd order polynomial regression, the curve fit throughout the entire length range of observed data (Fig. 15). Weight-on-length relationship for female onaga was fitted using a 3rd order polynomial regression (Table 2).

WL and LW relationships for Pacific blue marlin, striped marlin, and longnose lancetfish from Hawaiian waters were summarized in Table 4 and plotted in Figures 18-20. WL and LW relationships for snake mackerel were fitted by simple power function (Table 4). The longnose lancetfish and snake mackerel are bycatch, but they are important forage for tunas and billfishes (Reintjes and King, 1953; King and Ikehara, 1956; Waldron and King, 1963; and Nakamura, 1985).

In Appendix Table 1, WL relationships were fitted for five billfishes measured at fish auctions. A difference in WL relationships between sexes for striped marlin was significant (n = 1278, r^2 = 0.7891, intercept P = 0.000, slope: P = 0.000, length range 93-183 cm EFL), so separate WL relationships were fitted for females and males. The bias in weight due to the lack of bill weight is unknown and should be investigated on future cruises. Plots of WL relationships for these five billfishes were prepared showing observed measurements and fitted curve (Appendix Figures 1-5).

Kume and Joseph (1969) calculated gilled-and-gutted body weight-on-EFL and whole weight-on-EFL relationships for striped marlin, Pacific blue marlin, swordfish, sailfish, and the shortbill spearfish caught by longline in the eastern Pacific Ocean. Wares and Sakagawa (1974) also provided WL relationships for the eastern Pacific striped and Pacific blue marlins in their comparisons of WL and other morphometric relationships of fish landed at the San Diego Marlin Club, San Diego, California; Rancho Buena Vista in the territory of Baja California Sur, Mexico; and the Star Fleet at Mazatlán, Sinaloa, Mexico. A WL relationship of striped marlin caught off Baja California Sur, Mexico by sport fishing boats was described by Ponce Diaz et al. (1991). These results are mentioned here to supplement the list of literature mentioned in the introduction because these striped marlin caught in the eastern North Pacific Ocean and in Hawaii may belong to the same stock unit. Striped marlins tagged in the eastern North Pacific Ocean have been recaptured at and near the Hawaiian Islands (Squires, 1974, 1987).

In this study, WL predictors for billfishes, incidentally caught species, and bycatch species were based on small sample sizes. One objective of this exercise was to point out where deficiencies in our data exist. Pelagic species not appearing in this report were either lacking in our catch, just measured for length, or the number of paired measurements for a species were too small to calculate a meaningful relationship. Usually data were incomplete; i.e., the fish either was not weighed, not sexed, or an alternate length was measured. Billfishes were measured three different ways by different personnel on research cruises. Future measurements on billfishes should include both EFL and lower jaw fork length so length-to-length conversion formulas can be established. Skillman and Yong (1974) mentioned the possibly unreliable sex identification of Pacific blue marlins at sea. Therefore, gonad samples of marlins and whole bycatch species should be brought back for sex and species verification. Sharks, the opah, *Lampris guttatus*, the bramids, and seamount species are being studied by others.

The lack of data on bycatch species occasionally caught by longline, handline, or trolling became obvious during preparation of this report. The longnose lancet fish and snake mackerel caught by longline, and blackspot wrasse, oʻopu kai nohu, and purple snake mackerel caught on handline were the only bycatch or incidentally caught species collected in sufficient numbers to analyze. The life history of the purple snake mackerel, also called roudi escolar, caught on handline and deep longline off the Canary Islands in the Atlantic Ocean, was studied by Lorenzo and Pajuelo (1999), who used TL to measure fish, so our WL relationship cannot be directly compared. On past cruises, the emphasis was placed on target species such as tunas, billfishes, snappers, jacks, and groupers, and bycatch and incidentally caught species were processed only when time was available. Data acquisition for bycatch species may have been limited because type and use of gear result in selective catches. Future cruises should emphasize collecting data and samples of bycatch species because information on these species is needed for pending ecosystem models and food web analyses. Recording of uncommon bycatch species must be done carefully because analyses of these species may have to be performed on the limited data available.

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Table 1. Comparisons of intercepts and slopes for log-linearized weight-on-length relationships between sexes for members of the families Lutjanidae, Carangidae, and Scombridae. The comparison was performed by multiple regression, and the significance of differences in intercepts and slopes in the models were determined by an ANOVA test using the conditional sums of squares.

			Significance of terms in model		Length range (cm)	
Species	*n*	r^2	intercepts	slopes	min	max
Etelis carbunculus	1136	0.9714	P = 0.85	P = 0.67	23	60
E. coruscans	84	0.9679	P = 0.053	P = 0.24	54	80
Lutjanus kasmira	126	0.9681	P = 0.19	P = 0.69	19	42
Pristipomoides filamentosus	1247	0.9879	P = 0.058	P = 0.38	25	80
P. sieboldii	288	0.9072	P = 0.26	P = 0.33	24	41
P. zonatus	161	0.9462	P = 0.001	P = 0.66	31	46
Pseudocaranx dentex	474	0.9682	P = 0.03	P = 0.98	42	84
Seriola dumerili	211	0.9780	P = 0.66	P = 0.73	50	106
Euthynnus affinis	545	0.9627	P = 0.26	P = 0.22	33	75
Katsuwonus pelamis	107	0.9790	P = 0.13	P = 0.14	43	76
Thunnus alalunga	46	0.8440	P = 0.71	P = 0.75	90	109
T. albacares	238	0.9848	P = 0.43	P = 0.49	48	151
T. obesus	47	0.9879	P = 0.53	P = 0.60	66	157

Table 2. Nonlinear fork-length(FL)-on-whole weight(W) and whole weight-on-fork-length relationships for snappers and grouper from the Northwestern Hawaiian Islands using data collected on the NOAA ship *Townsend Cromwell* from 1977 to 1993. *n* = number of fish.

		Model $Y=aX^b$			Exponent		Constant		Size range			
									Weight (kg)		Length (cm)	
Species	Relation	r^2	s.e.	*n*	***b***	s.e.	***a***	s.e.	Min	Max	Min	Max
Etelis carbunculus	W on FL	0.960	0.167783	1221	3.00985	0.0173759	1.71379E-5	1.23927E-6	0.09	4.70	18.6	64.1
sexes pooled	FL on W	0.970	1.32933	1221	0.32023	0.0016736	38.5895	0.0486324				
E. coruscans	W on FL	0.977	0.377301	123	2.69544	0.0410238	5.5096E-5	1.03539E-5	0.33	10.7	26.5	93.5
sexes pooled	FL on W	0.986	1.67289	123	0.35087	0.0042778	39.3948	0.294213				
females	W on	0.972	0.397559	74					0.77	10.7	36.8	93.5
	FL on W	0.975	1.84342	74	0.35157	0.0069965	39.3199	0.509865				
males	W on FL	0.981	0.275072	41	2.76942	0.0700441	3.97791E-5	1.25828E-5	0.33	7.76	26.5	81.0
	FL on W	0.988	1.45907	41	0.35589	0.0068964	39.0982	0.412861				
Lutjanus kasmira	W on FL	0.988	0.0320814	164	3.20148	0.0199526	9.87336E-6	7.40726E-7	0.06	1.82	15.1	44.7
sexes pooled	FL on W	0.972	0.782982	164	0.30276	0.0035694	36.2894	0.160455				
Pristipomoides filamentosus	W on FL	0.982	0.266602	1531	2.79567	0.0140952	3.81465E-5	2.39335E-6	0.04	8.00	15.5	80.4
sexes pooled	FL on W	0.993	1.4463	1531	0.34481	9.5245E-4	38.7175	0.0519268				
females	W on FL	0.976	0.300611	616	2.79638	0.0222042	3.82701E-5	3.78499E-6	0.31	8.00	25.5	80.4
	FL on W	0.986	1.58986	616	0.34763	0.0018422	38.4939	0.0999682				
males	W on FL	0.970	0.28623	633	2.77212	0.0237627	4.18573E-5	4.40791E-6	0.28	7.67	25.5	77.6
	FL on W	0.982	1.53716	633	0.34819	0.0020709	38.606	0.111114				
P. sieboldii	W on FL	0.907	0.0753396	329	2.94162	0.0520394	2.18039E-5	4.31785E-6	0.20	1.50	22.6	43.5
sexes pooled	FL on W	0.915	1.12282	329	0.30618	0.0053938	38.1268	0.0838386				
P. zonatus	W on FL	0.935	0.116321	189	2.83294	0.0524424	4.08276E-5	8.48518E-6	0.63	3.00	31.0	50.3
sexes pooled	FL on W	0.947	1.01982	189	0.32799	0.0057784	35.7813	0.103763				
females	W on FL	0.908	0.121154	83	2.8417	0.0982989	4.04118E-5	1.56429E-5	0.63	2.19	31.0	46.9
	FL on W	0.922	1.07287	83	0.31482	0.0104277	35.6711	0.174565				
males	W on FL	0.944	0.113337	84	2.92815	0.0766643	2.80176E-5	8.55994E-6	0.68	3.00	31.6	48.9
	FL on W	0.954	0.919379	84	0.32813	0.0075887	36.0734	0.1458				

*3rd order polynomial regression fit data best: $W = 9.42104 - 0.534971FL + 0.0097137FL^{2.00002} - 0.0000412611FL^{3.00073}$.

Table 3. Nonlinear-whole-weight(W)-on-fork length (FL) and fork length-on-whole-weight relationships for a grouper, carangids, a labrid, and a scorpaenid from the Northwestern Hawaiian Islands using data taken at handline stations on the NOAA ship *Townsend Cromwell* from 1977 to 1993. Total length (TL) was used for the grouper, labrid, and scorpaenid whose caudal fins are rounded or truncated. n = number of fish.

		Model $Y=aX^b$			Exponent		Constant		Size range			
									Weight (kg)		Length	
Species	Relation	r^2	s.e.	n	b	s.e.	a	s.e.	Min	Max	Min	Max
Epinephelus quernus	W on TL	0.9378	1.13788	80	3.02944	0.0267136	1.62089E-5	2.05365E-6	0.24	34.70	23.5	113.9
sexes pooled	TL on W	0.9749	2.50834	80	0.31581	0.0018863	39.2679	0.152807				
Pseudocaranx dentex	W on FL	0.9521	0.50349	50	2.86839	0.0291936	3.09675E-5	4.13087E-6	0.71	11.56	33.3	89.0
sexes pooled	FL on W	0.9664	1.86304	50	0.33064	0.0028913	38.5337	0.200372				
females	W on FL	0.9427	0.56915	23	2.85046	0.0461982	3.32027E-5	7.02837E-6	1.23	11.56	40.1	89.0
	FL on W	0.9596	2.05141	23	0.32949	0.0046253	38.7168	0.326017				
males	W on FL	0.9608	0.44271	24	2.8974	0.038813	2.7623E-5	4.8873E-6	1.25	10.70	41.7	85.1
	FL on W	0.9708	1.69266	24	0.33124	0.0038529	38.368	0.263877				
Seriola dumerili	W on FL	0.9634	0.7920	22	2.79692	0.0346592	3.67659E-5	6.10917E-6	1.77	20.5	49.4	113.8
sexes pooled	FL on W	0.9763	2.27991	22	0.33930	3.52333E-3	40.0331	0.297914				
Bodianus bilunulatus	W on TL	0.9480	0.17608	36	3.11581	0.124003	1.23942E-5	6.25465E-6	0.26	3.30	23.9	54.5
sexes pooled	TL on W	0.9771	1.1625	36	0.30822	0.0081400	37.7535	0.20097				
Pontinus macrocephalus	W on TL	0.9133	0.16352	48	3.18325	0.13544	8.37454E-6	4.59637E-6	0.26	2.51	28.9	53.0
sexes pooled	TL on W	0.9322	1.46624	48	0.27471	0.0110069	39.7307	0.218423				
Promethichthys prometheus	W on FL	0.9404	1.18602	38	3.13661	0.140839	3.13403E-5	1.92232E-5	0.40	20.00	21.1	68.9
sexes pooled	FL on W	0.9500	2.67522	38	0.30342	0.0116009	28.03	0.639846				

Table 4. Nonlinear whole-weight(W)-on-fork length(FL) and fork length-on-whole-weight relationships for tunas, billfishes, and bycatch species from the Hawaii area using data collected on the NOAA ship *Townsend Cromwell* from 1977 to 2002. *n* = number of fish.

Species	Relation	Model $Y=\boldsymbol{a}X^{\boldsymbol{b}}$ r^2	s.e.	*n*	Exponent ***b***	s.e.	Constant ***a***	s.e.	Range Weight (kg) Min.	Max	Length (cm) Min.	Max.
Euthynnus affinis	W on FL	0.9670	0.371277	610	2.9908	0.0212224	2.10627E-5	1.9767E-6	0.4	12.8	27.8	79.9
sexes pooled	FL on W	0.9708	1.81485	610	0.321539	0.00222213	37.191	0.109928				
Katsuwonus pelamis	W on FL	0.9792	0.411365	115	3.24281	0.0451783	7.64751E-6	1.55984E-6	1.4	10.4	42.5	78.6
sexes pooled	FL on W	0.9818	1.51512	115	0.297621	0.0036523	38.4787	0.220609				
Thunnus alalunga	W on FL	0.9811[a]	1.36489	143[b]					3.4	37.2	56.0	127.3
sexes pooled	FL on W	0.9868	2.20089	143	0.329981	0.00341728	37.0396	0.382638				
Thunnus albacares	W on FL	0.9751	2.20715	359	2.88938	0.0218593	3.16534E-5	3.62261E-6	1.8	93.4	47.2	165.8
sexes pooled	FL on W	0.9858	2.87083	359	0.3345023	0.00189607	37.3944	0.196213				
Thunnus obseus	W on FL	0.9789	3.14931	62	2.93652	0.0652944	2.77562E-5	9.62417E-6	2.5	95.2	48.4	166.1
sexes pooled	FL on W	0.9877	3.03362	62	0.334073	0.00552319	36.5004	0.770417				
Makaira mazara	W on EFL	0.9853	10.4811	32[c]	3.43209	0.0613445	1.34548E-6	4.9997E-7	12.7	455.4	110.2	303.2
sexes pooled	EFL on W	0.9665	7.88406	32	0.287073	9.29126E-3	51.9063	2.299				
Tetrapturus audax	W on EFL	0.9621	3.09274	17	3.41344	0.162934	1.33263E-6	1.22426E-6	8.6	68.0	101.5	178.2
sexes pooled	EFL on W	0.9526	4.71683	17	0.269533	0.0150584	57.1284	2.91644				
Alepisaurus ferox	W on FL	0.9428	0.423562	200	2.75849	0.0705059	6.01421E-6	2.21698E-6	0.04	6.6	27.0	152.5
sexes pooled	FL on W	0.9668	5.72415	200	0.344511	5.12776E-3	79.5995	0.513094				
Gempylus serpens	W on FL	0.8988	0.201255	11	2.53172	0.281737	1.19631E-5	1.68632E-5	0.48	2.4	70.3	124.7
sexes pooled	FL on W	0.9126	5.02301	11	0.342512	0.0370063	89.8671	1.87116				

[a]second order polynomial model: $\mathbf{W} = 6.16388 - 0.323931\mathbf{FL} + 0.00600216\mathbf{FL}^{1.94647}$

[b]data increased by adding measurements made on eastern North Pacific albacore.

[c]data increased by using published measurements (Royce 1957).

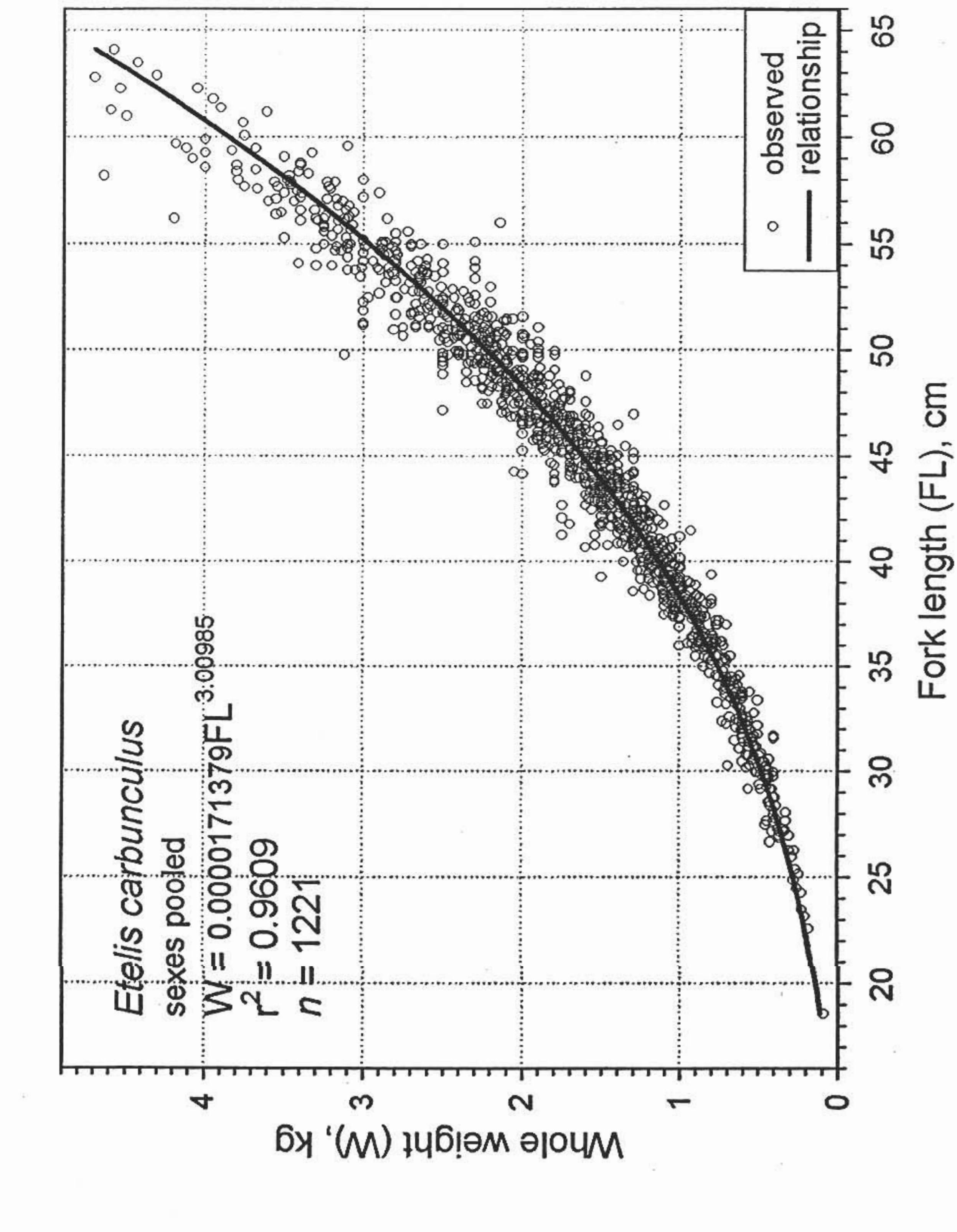


Figure 1. Weight-on-length relationship for ehu, *Etelis carbunculus*, from the Northwestern Hawaiian Islands.

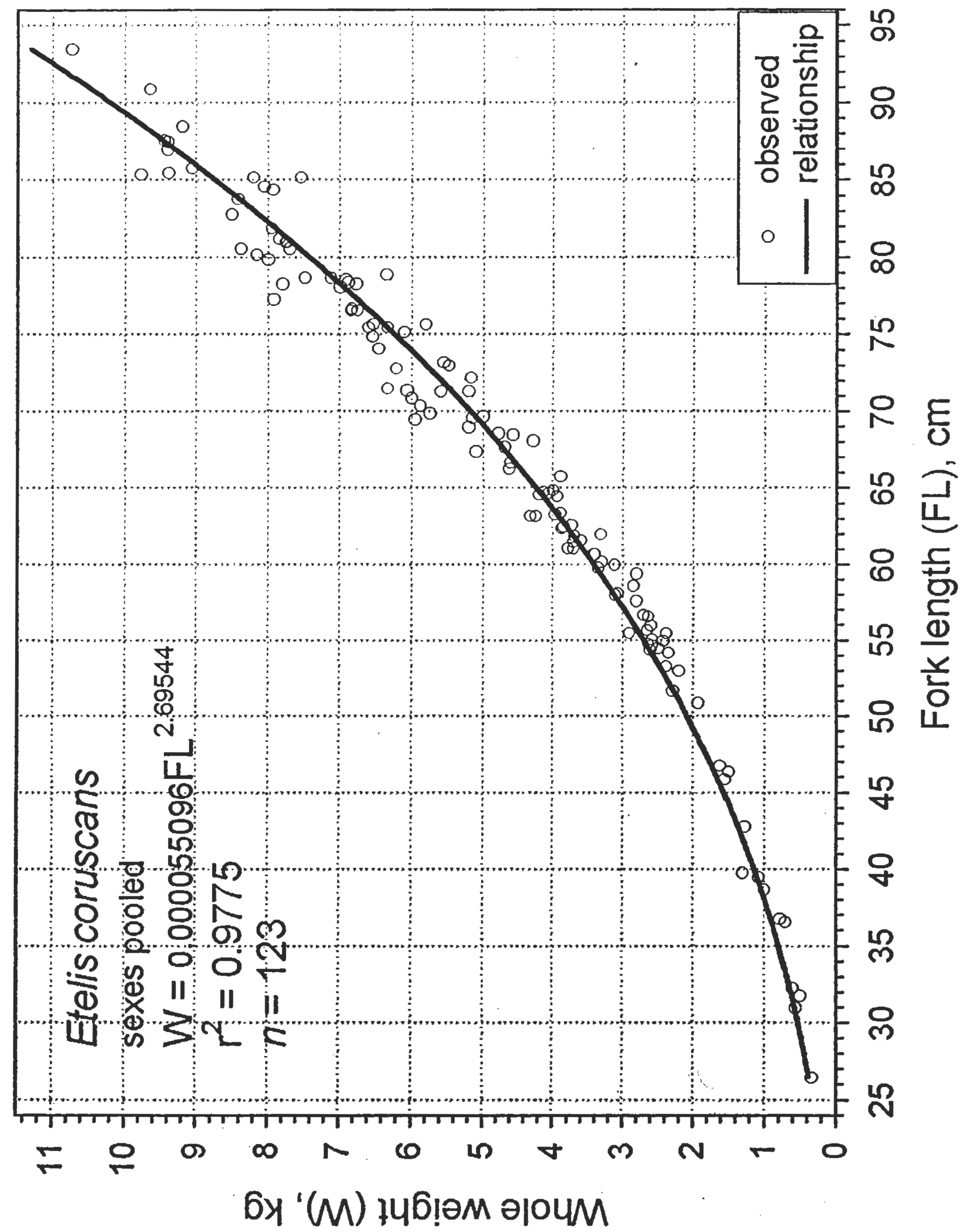


Figure 2. Weight-on-length relationship for onaga, *Etelis coruscans*, from the Northwestern Hawaiian Islands.

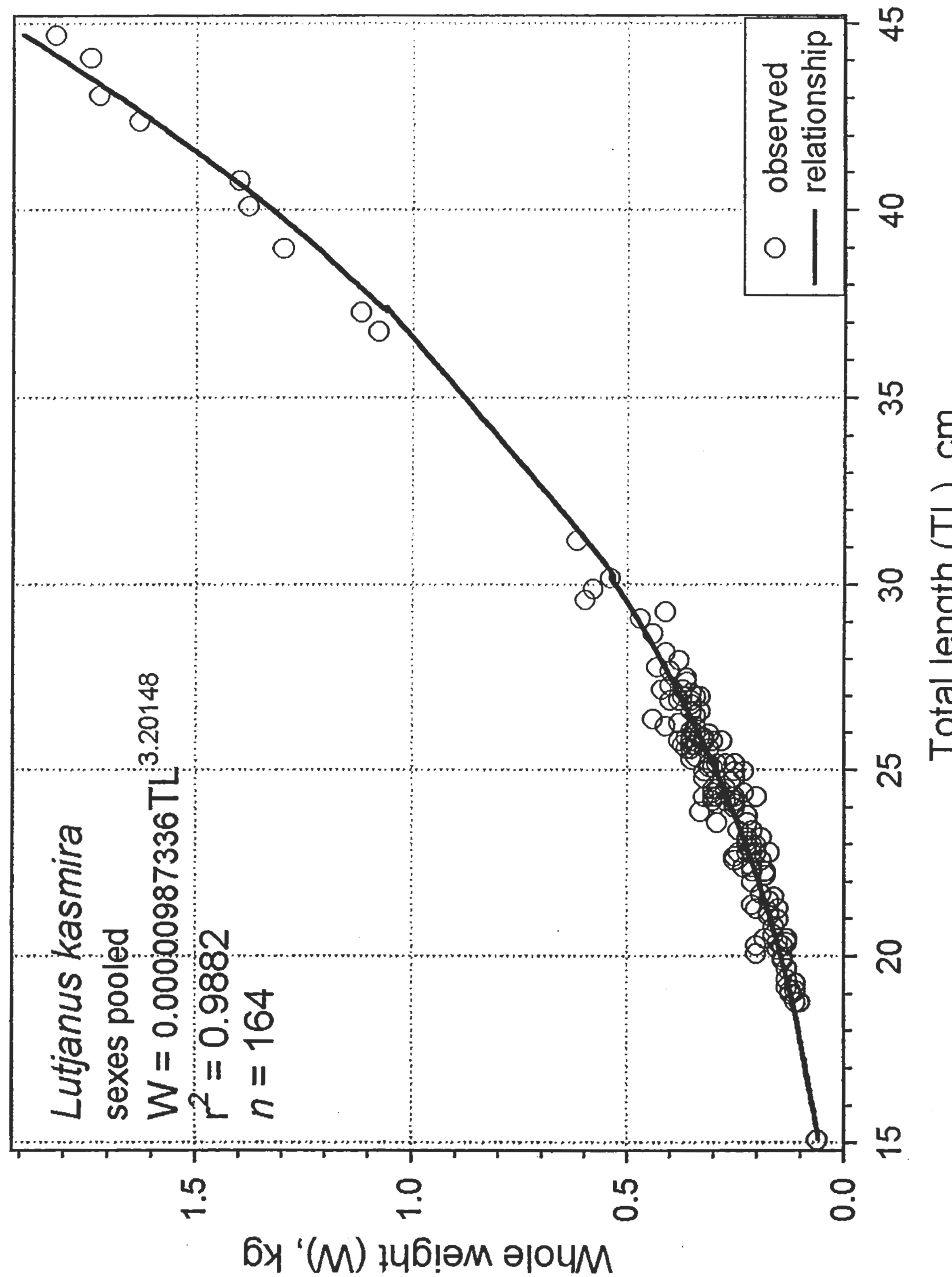


Figure 3. Weight-on-length relationship for ta'ape, *Lutjanus kasmira*, from the Northwestern Hawaiian Islands.

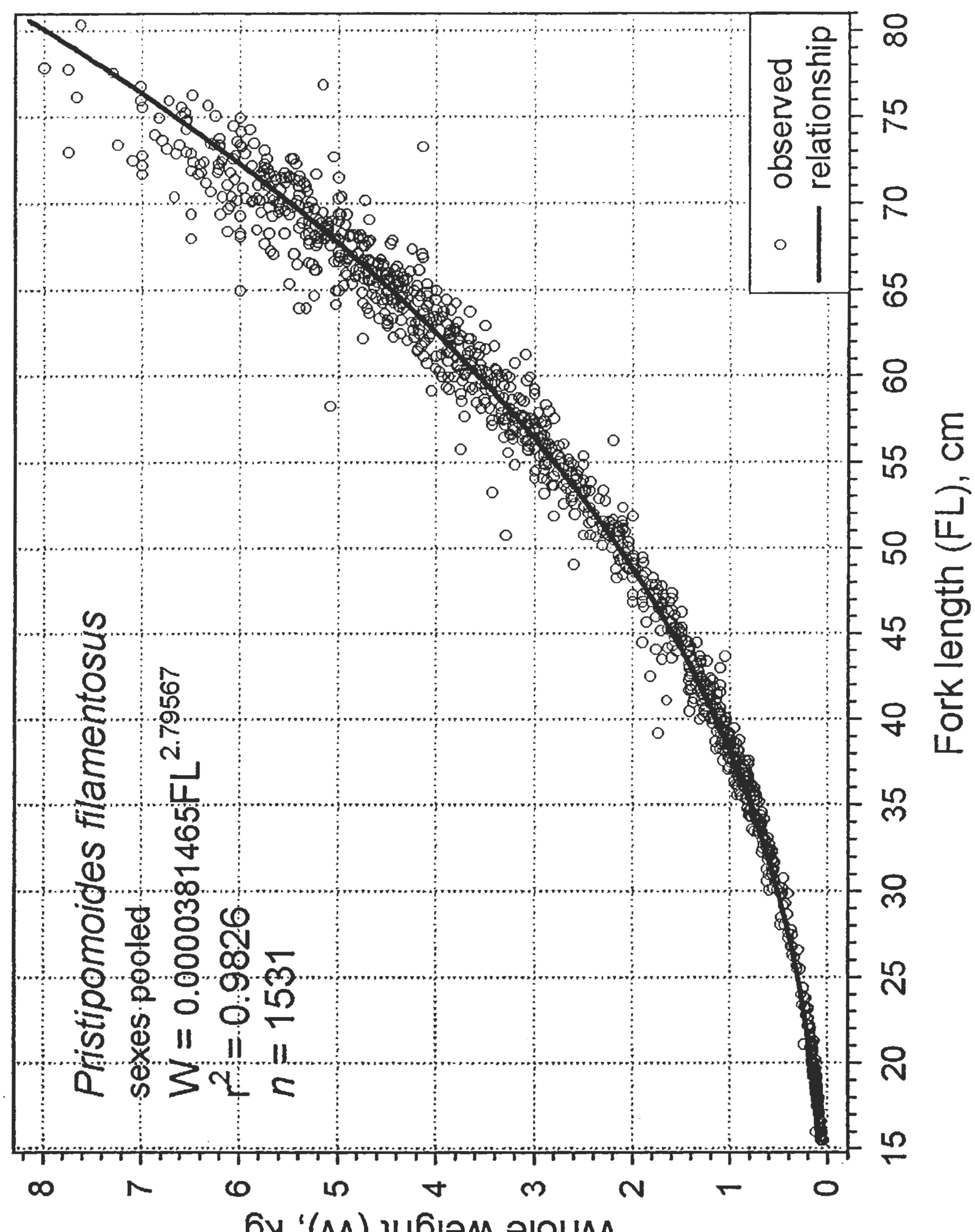


Figure 4. Weight-on-length relationship for ‘opakapaka, *Pristipomoides filamentosus*, from the Northwestern Hawaiian Islands.

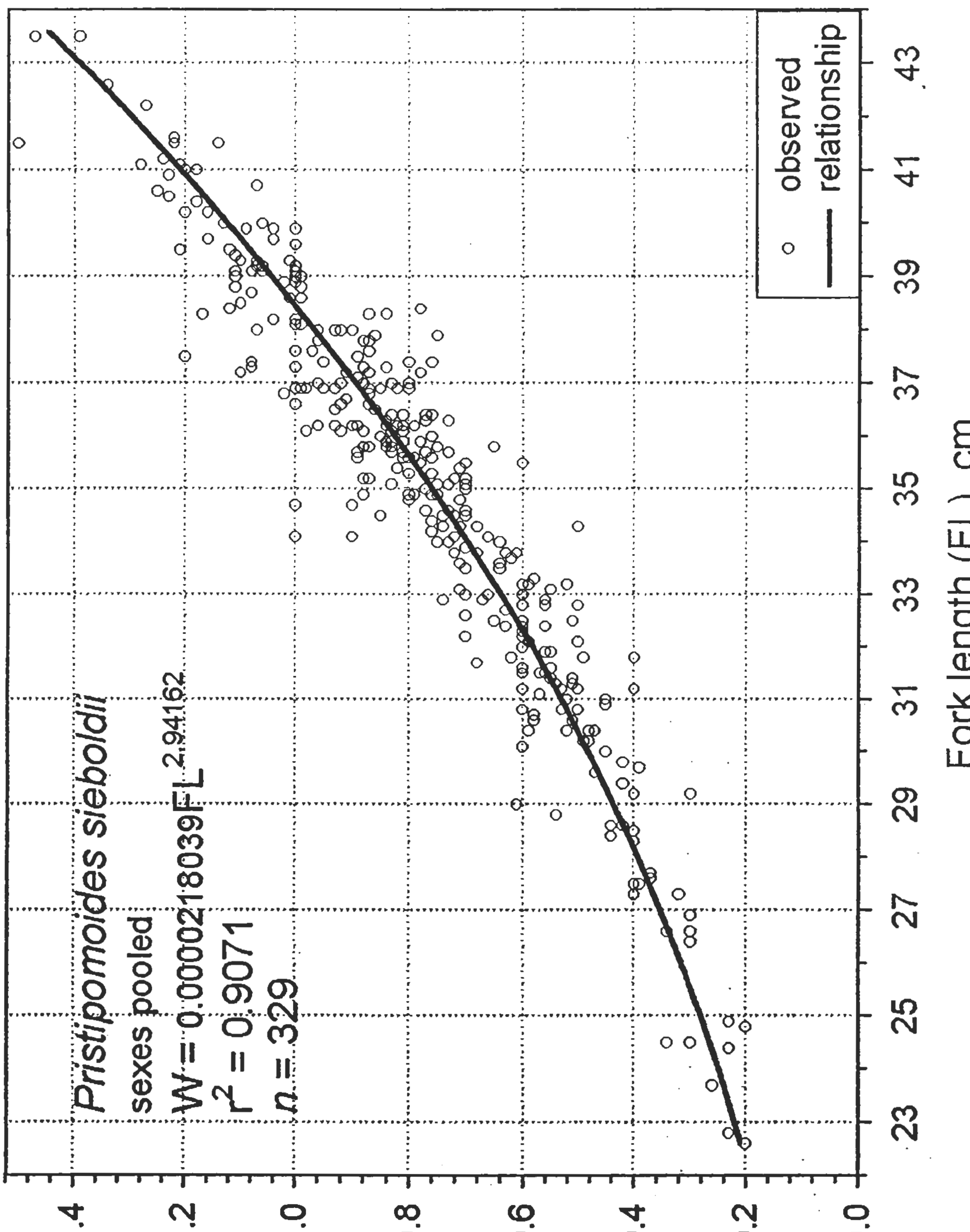


Figure 5. Weight-on-length relationship for kalekale, *Pristipomoides sieboldii*, from the Northwestern Hawaiian Islands.

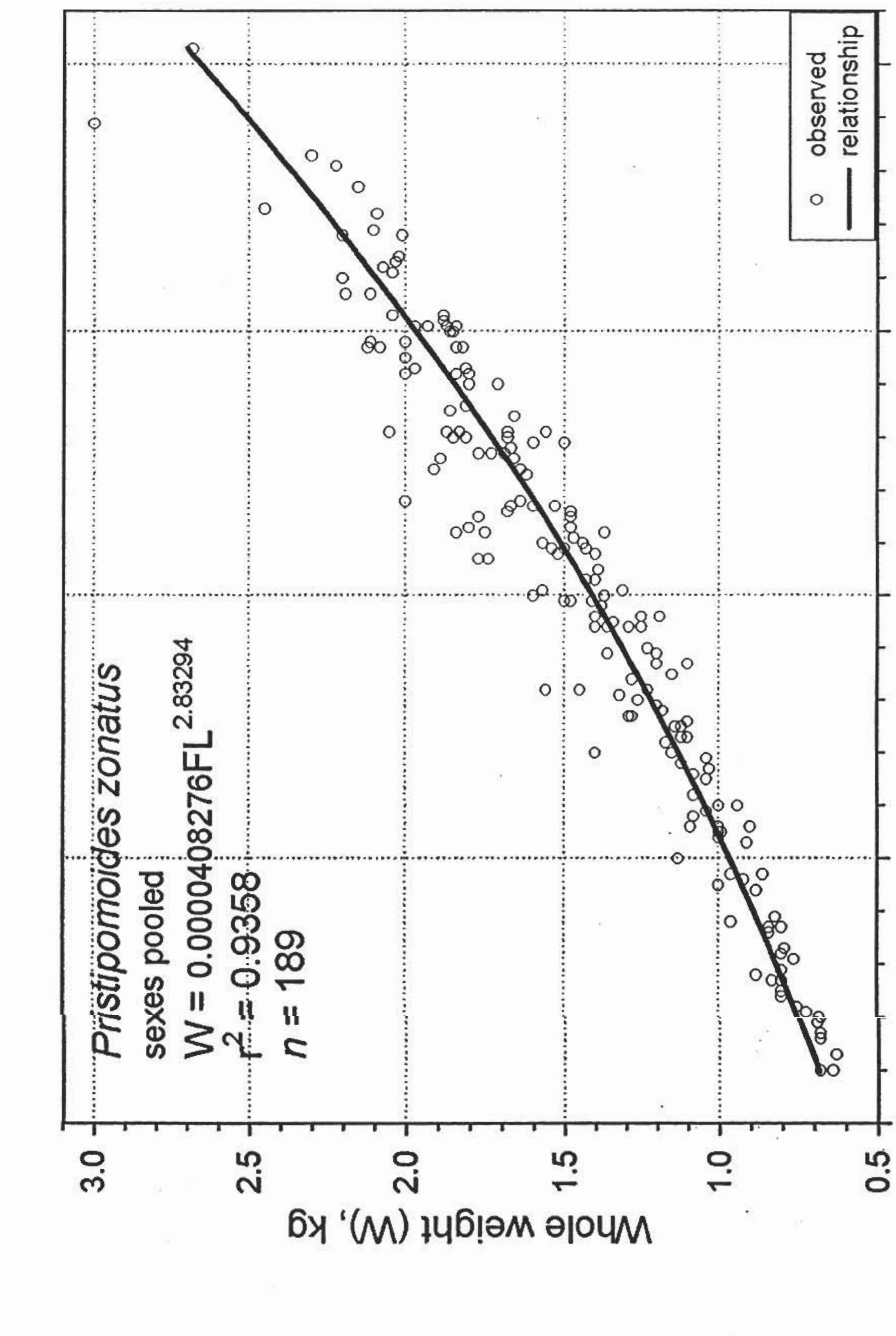


Figure 6. Weight-on-length relationship for gindai, *Pristipomoides zonatus*, from the Northwestern Hawaiian Islands.

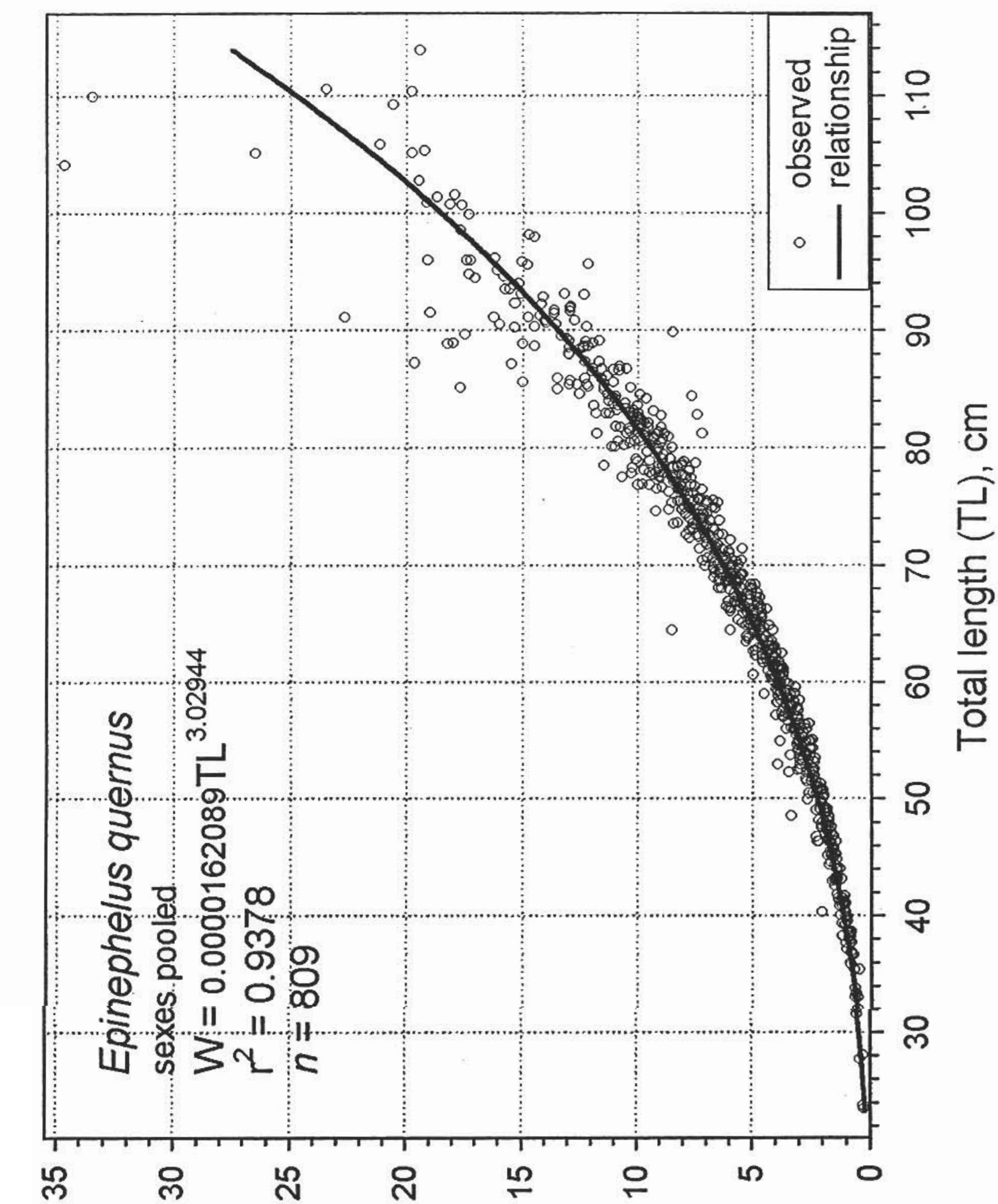


Figure 7. Weight-on-length relationship for hapu'u, *Epinephelus quernus*, from the Northwestern Hawaiian Islands.

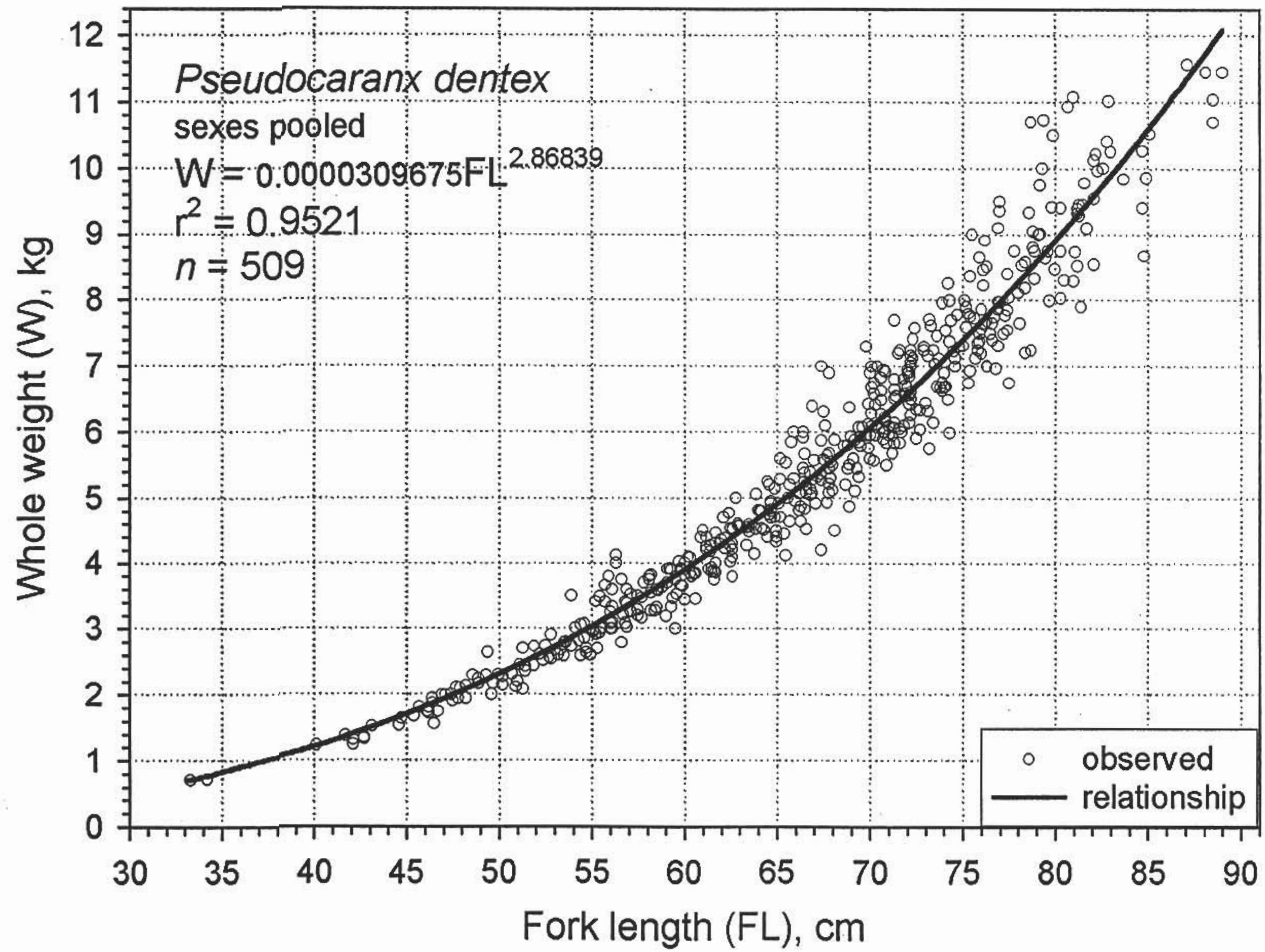


Figure 8. Weight-on-length relationship for butaguchi, *Pseudocaranx dentex*, from the Northwestern Hawaiian Islands.

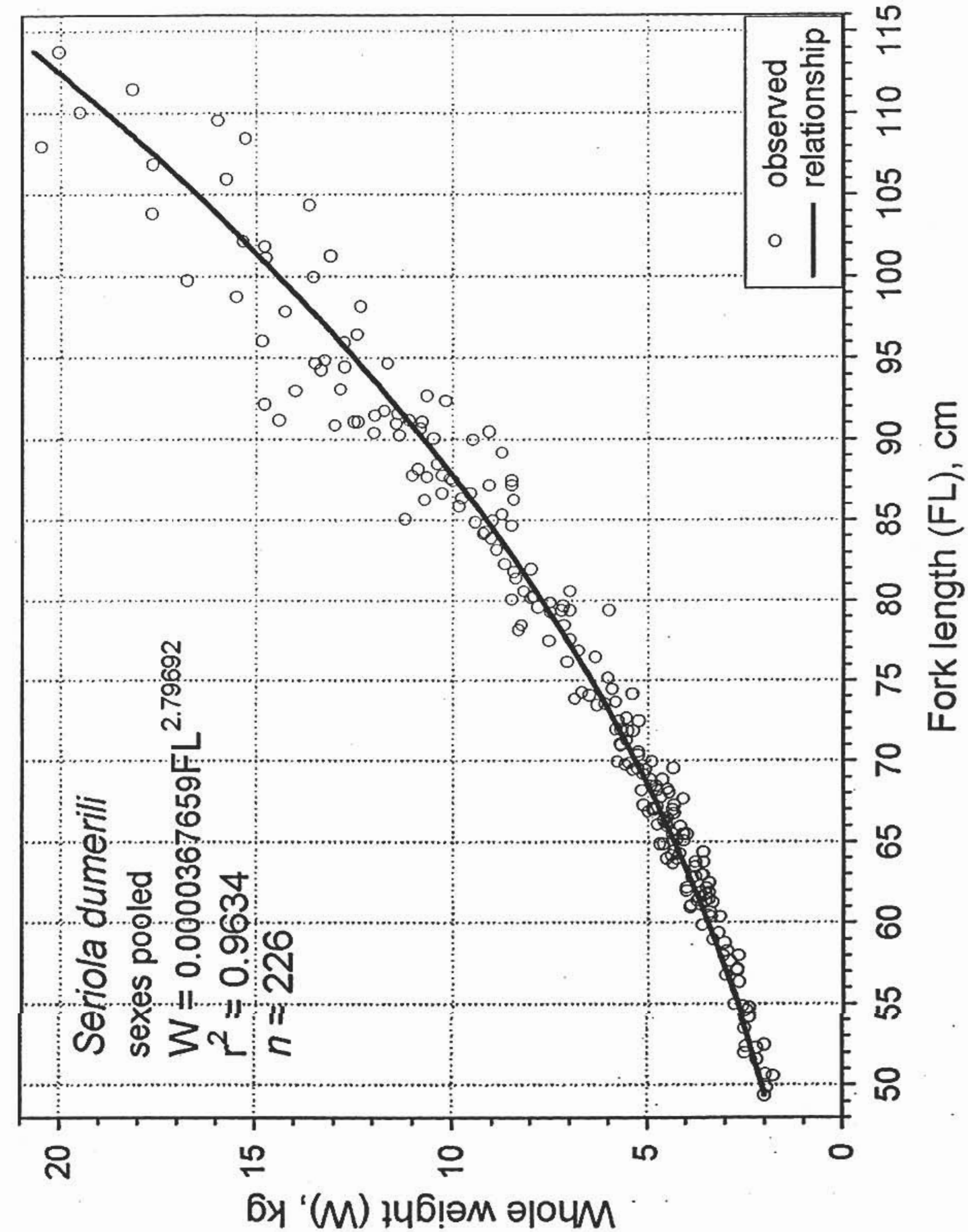


Figure 9. Weight-on-length relationship for kahala, *Seriola dumerili*, from the Northwestern Hawaiian Islands.

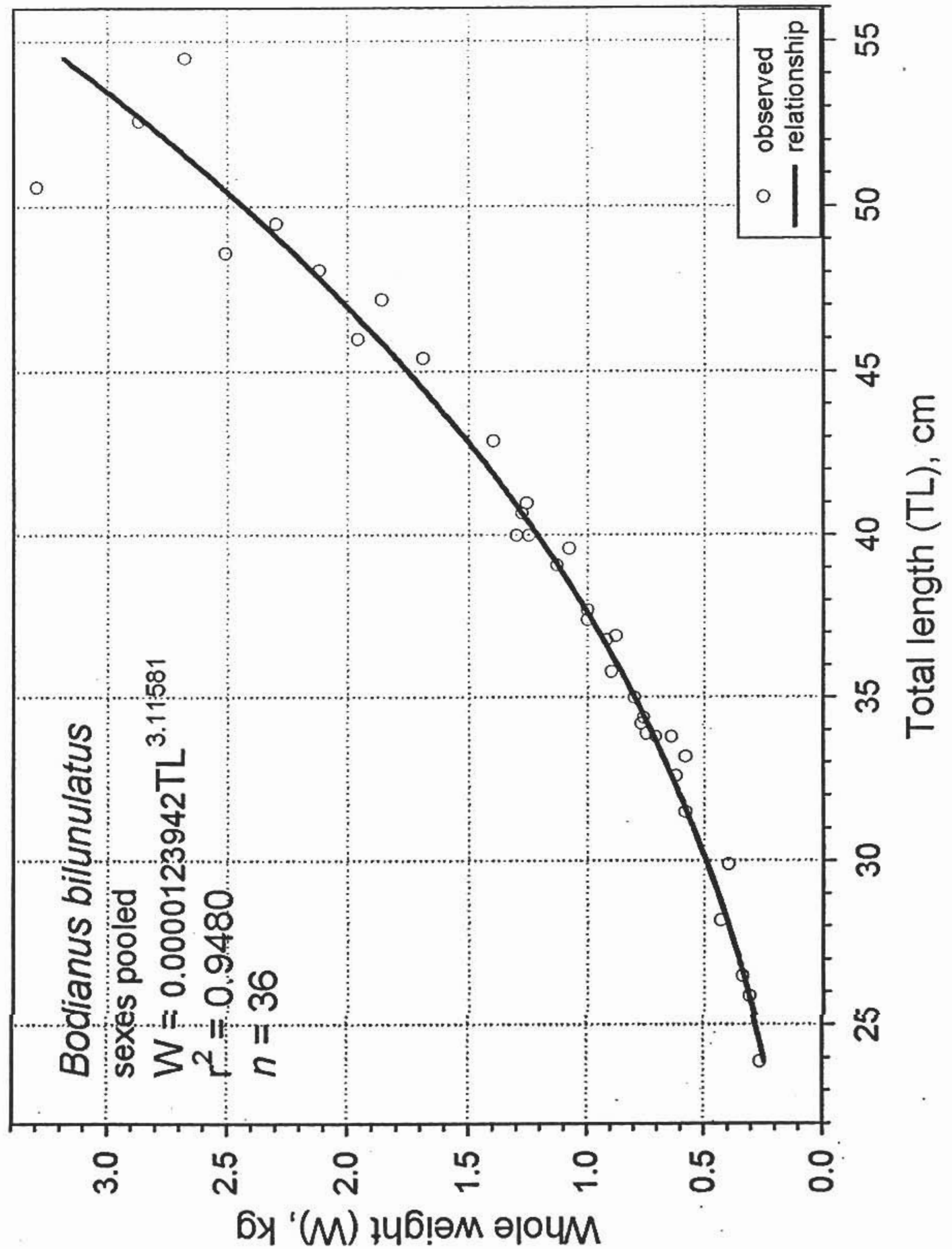


Figure 10. Weight-on-length relationship for the blackspot wrasse, *Bodianus bilunulatus*, from the Northwestern Hawaiian Islands.

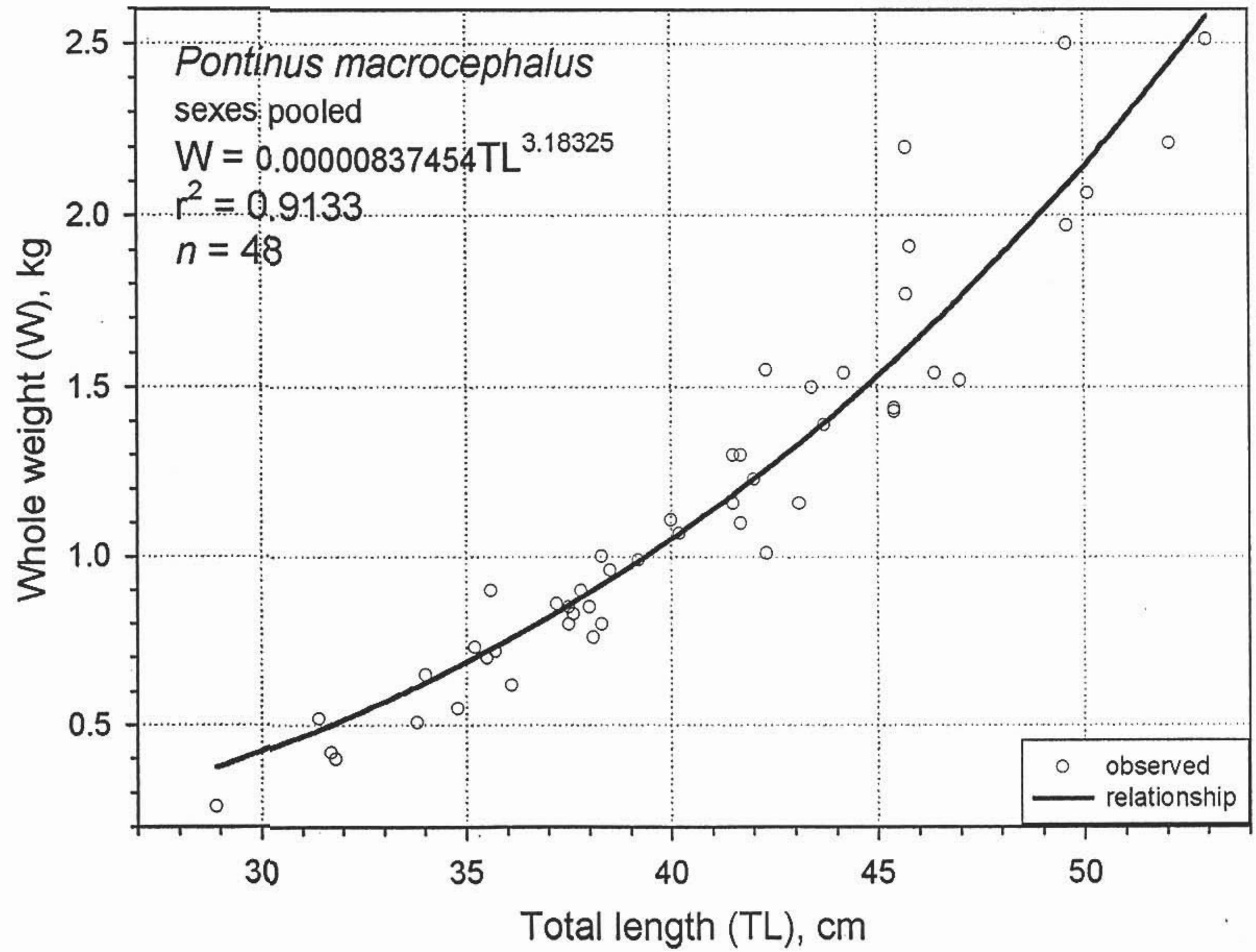


Figure 11. Weight-on-length relationship for o'opu kai nohu. *Pontinus macrocephalus*, from the Northwestern Hawaiian Islands.

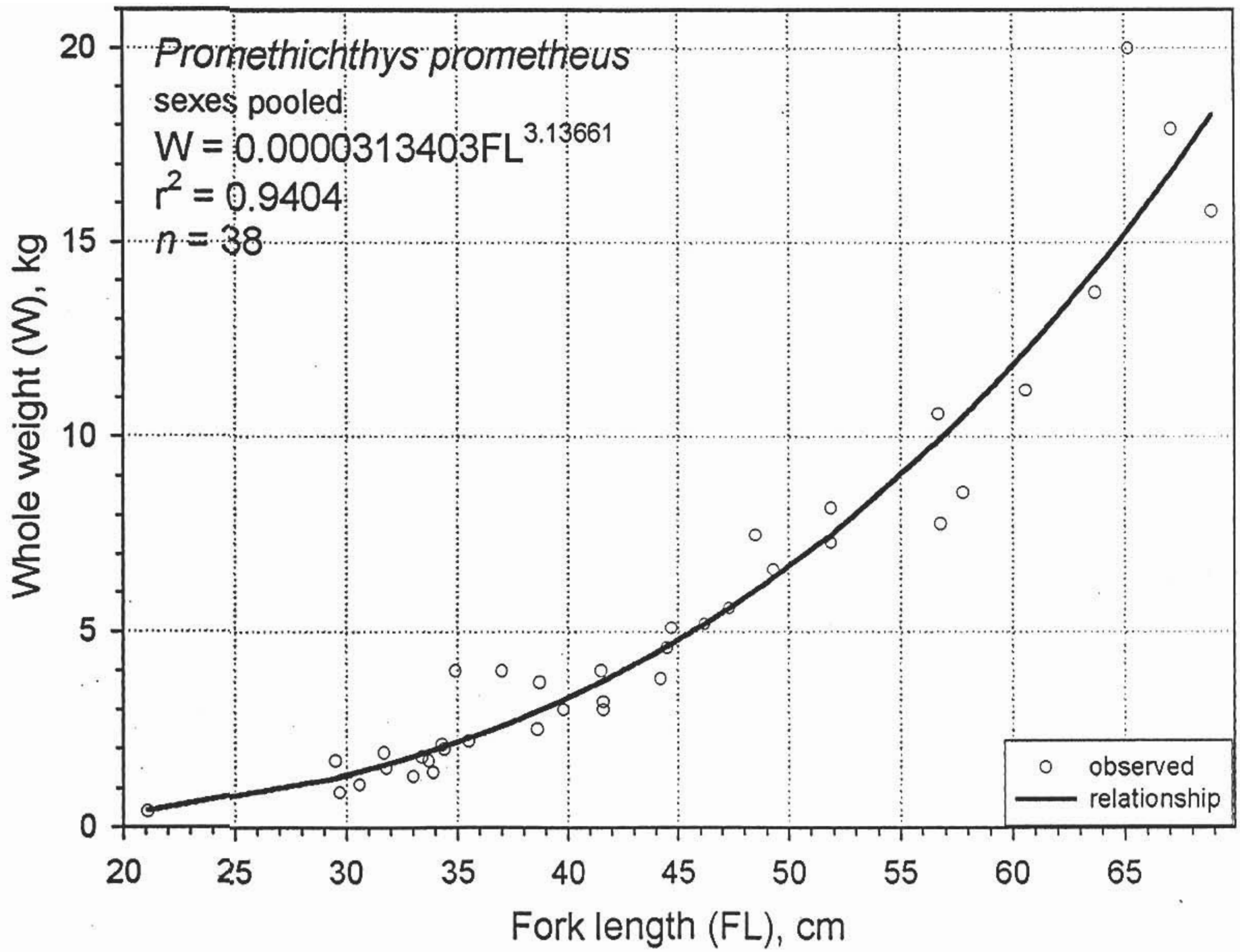


Figure 12. Weight-on-length relationship for purple snake mackerel, *Promethichthys prometheus*, from the Northwestern Hawaiian Islands.

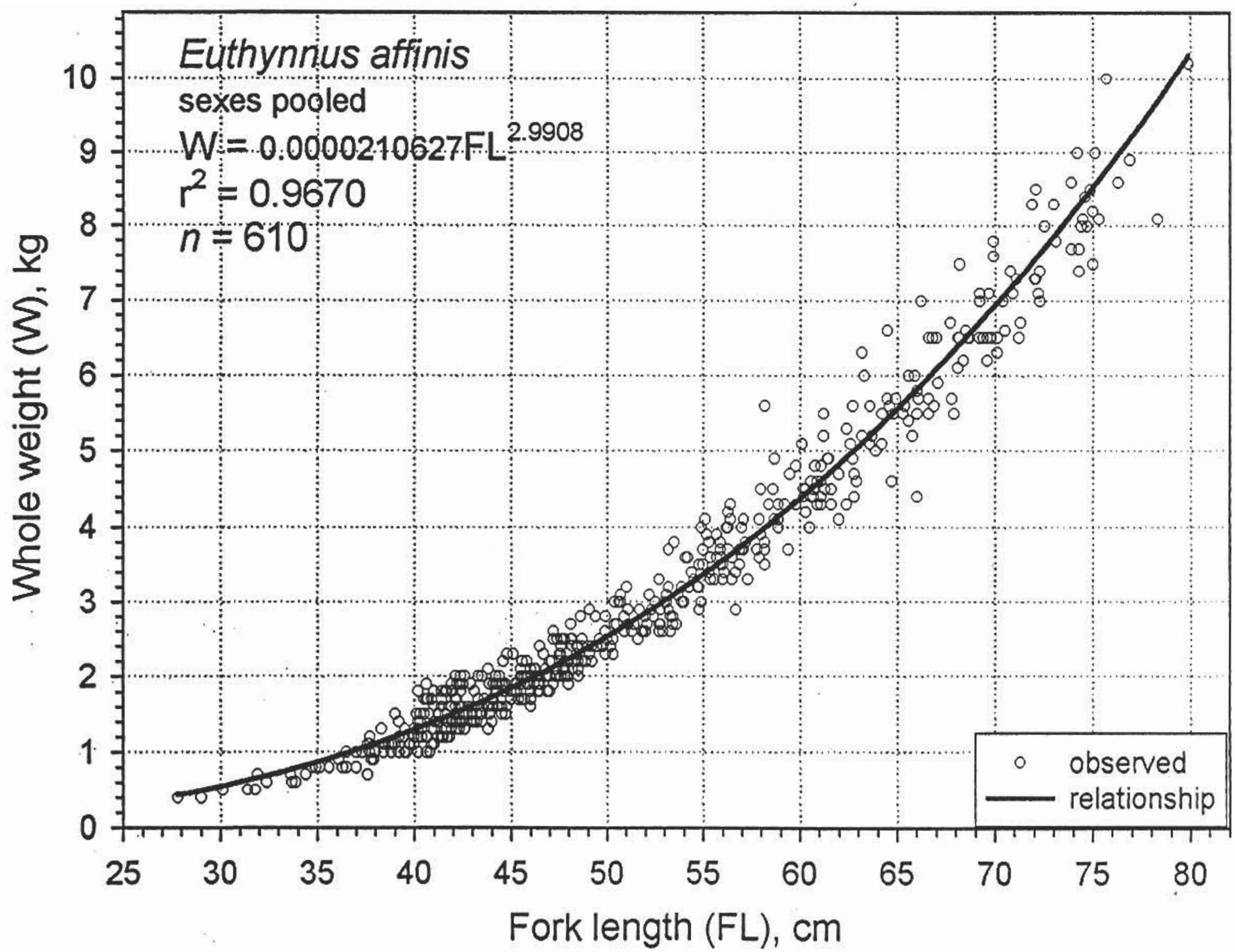


Figure 13. Weight-on-length relationship for kawakawa, *Euthynnus affinis*, from the Northwestern Hawiian Islands.

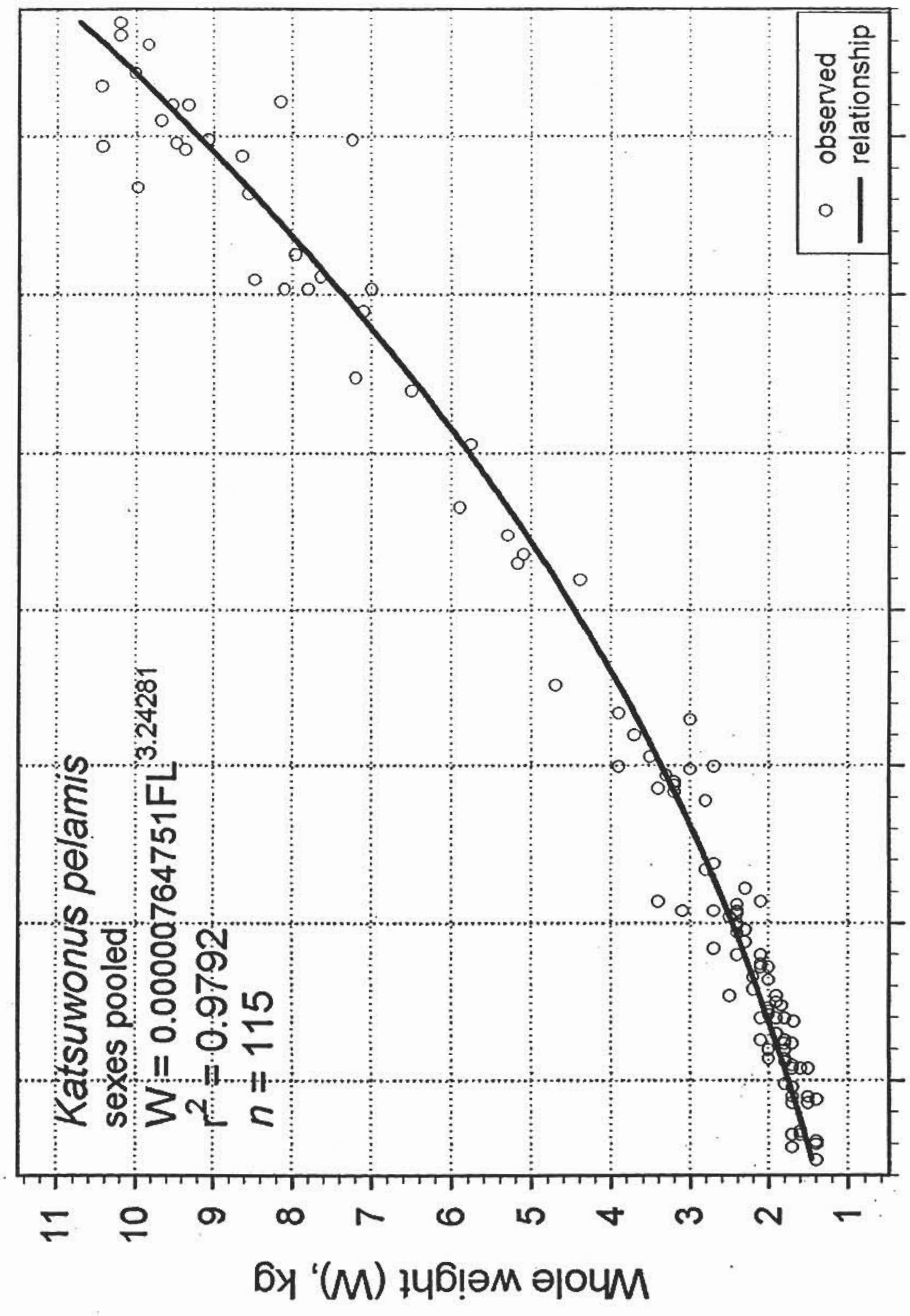


Figure 14. Weight-on-length relationship for aku, *Katsuwonus pelamis*, from the central North Pacific Ocean.

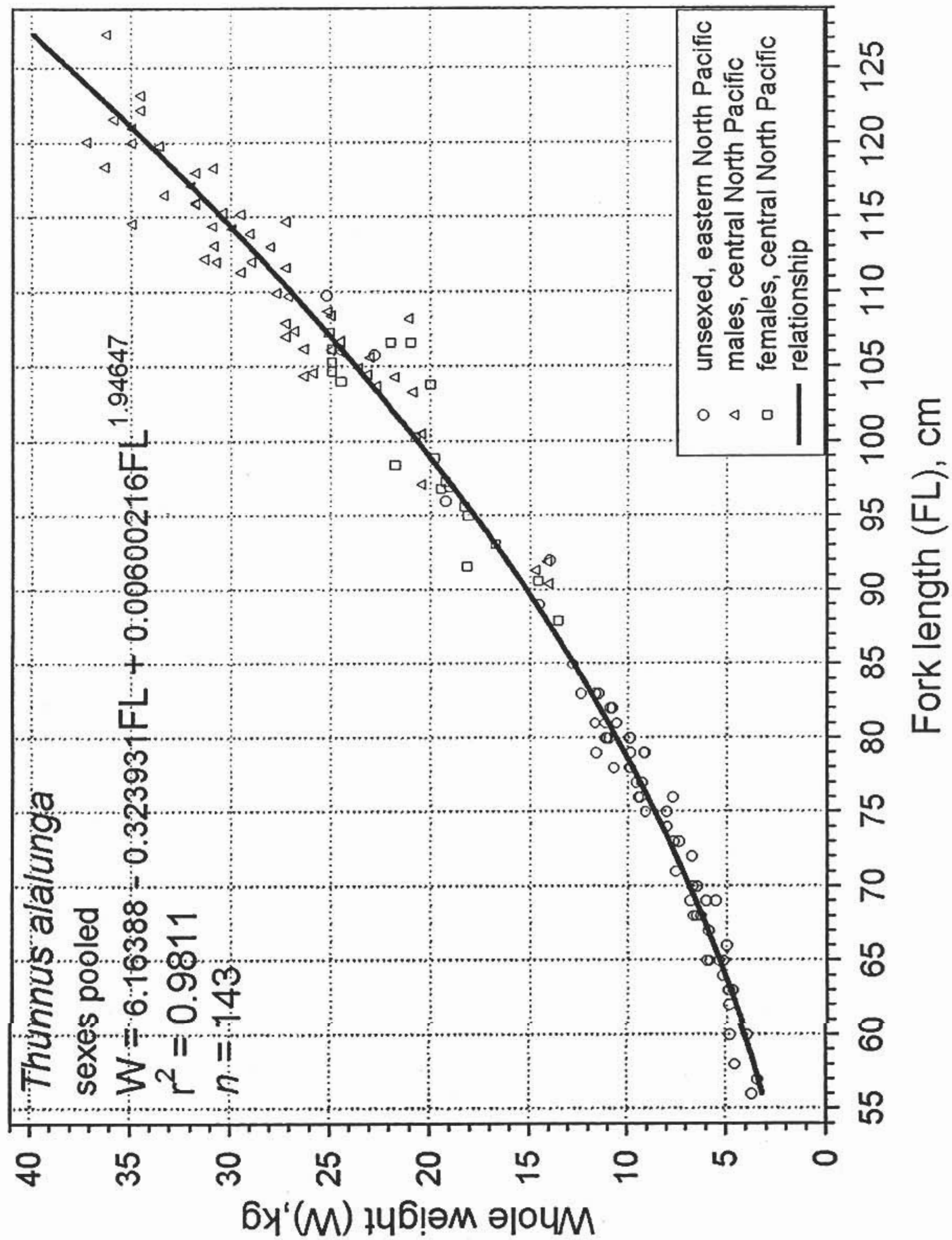


Figure 15. Weight-on-length relationship for albacore, *Thunnus alalunga*, from the eastern and central North Pacific Ocean.

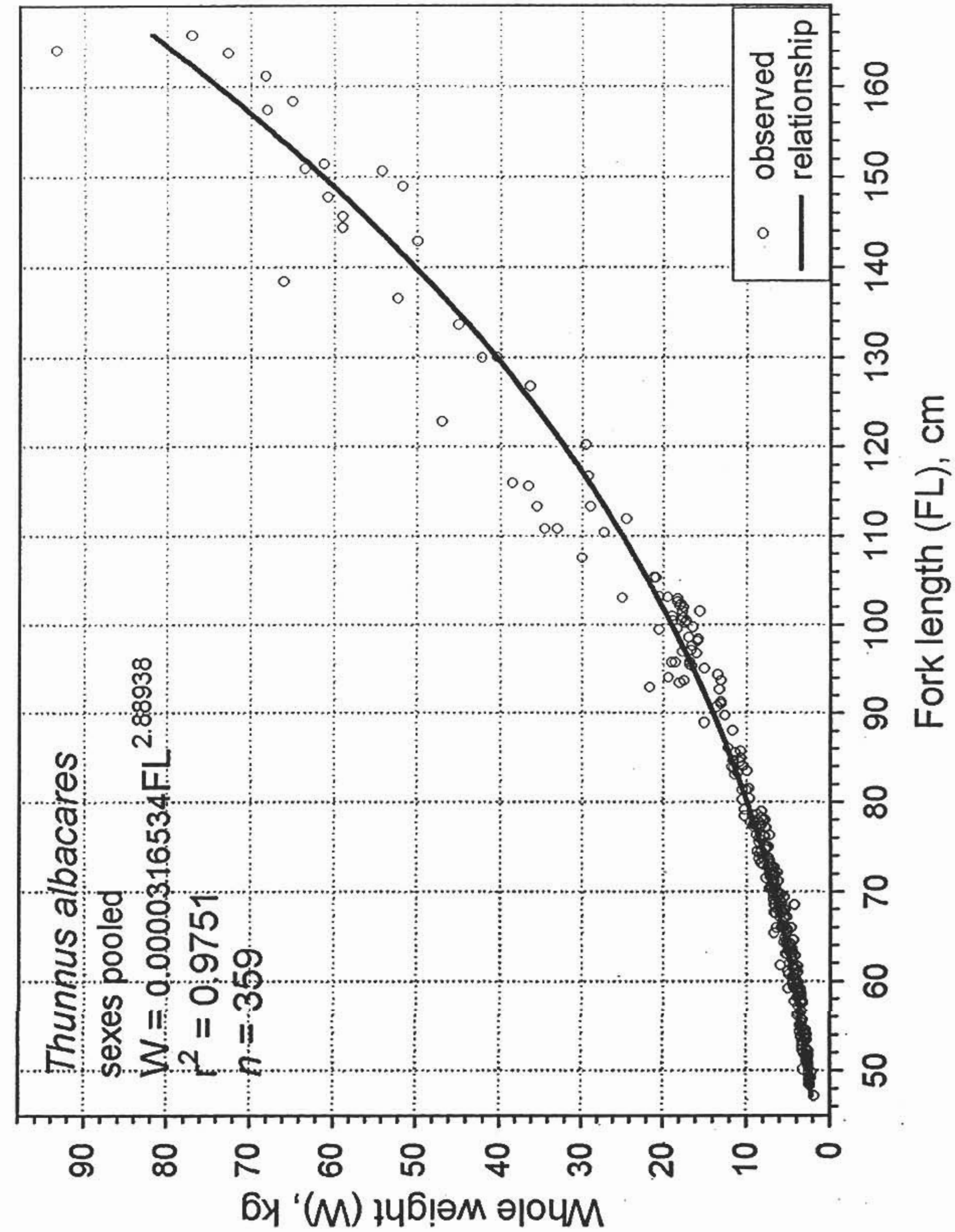


Figure 16. Weight-on-length relationship for ahi, *Thunnus albacares*, from the central North Pacific Ocean.

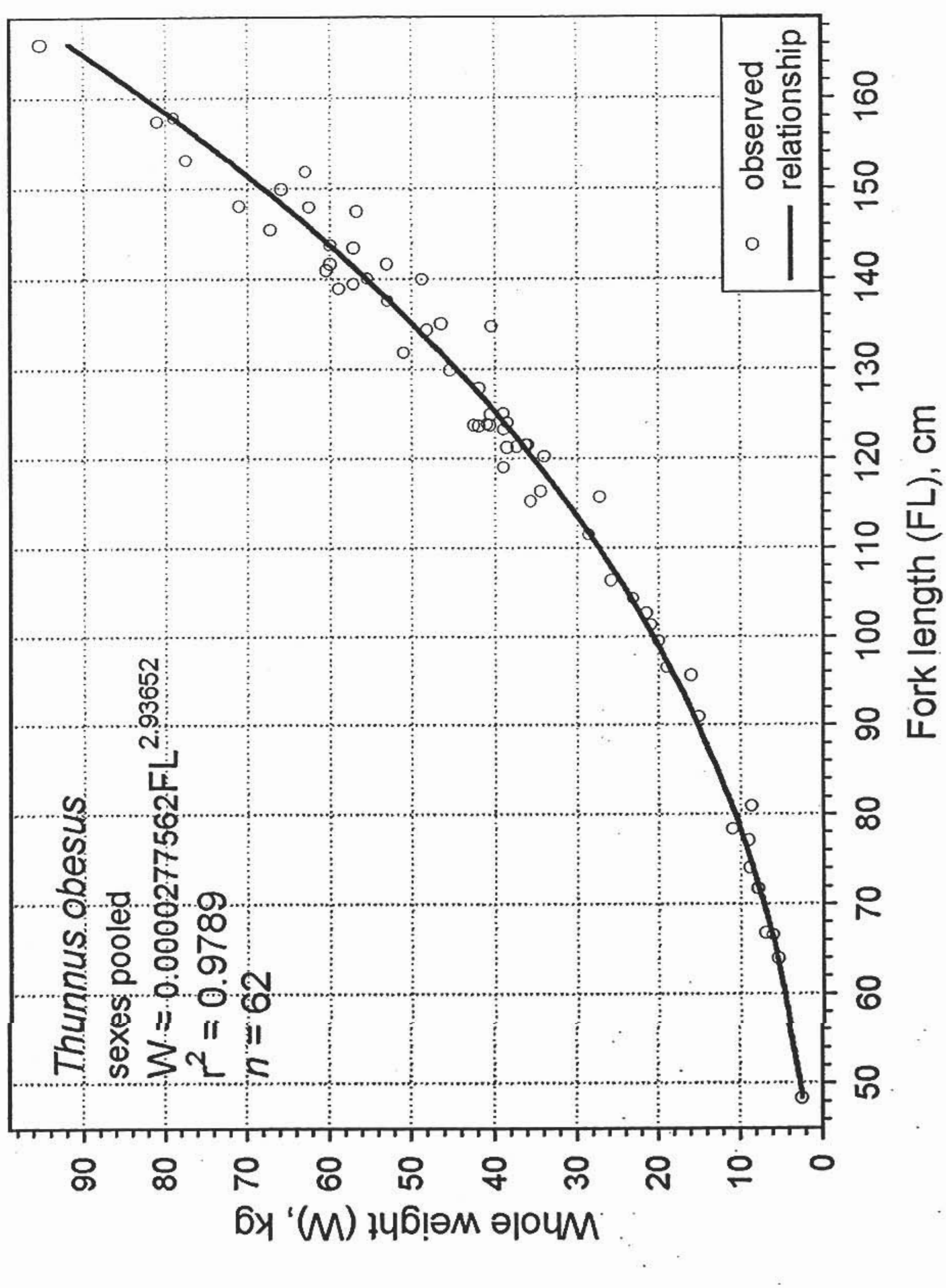


Figure 17. Weight-on-length relationship for bigeye tuna, *Thunnus obesus*, from the central North Pacific Ocean.

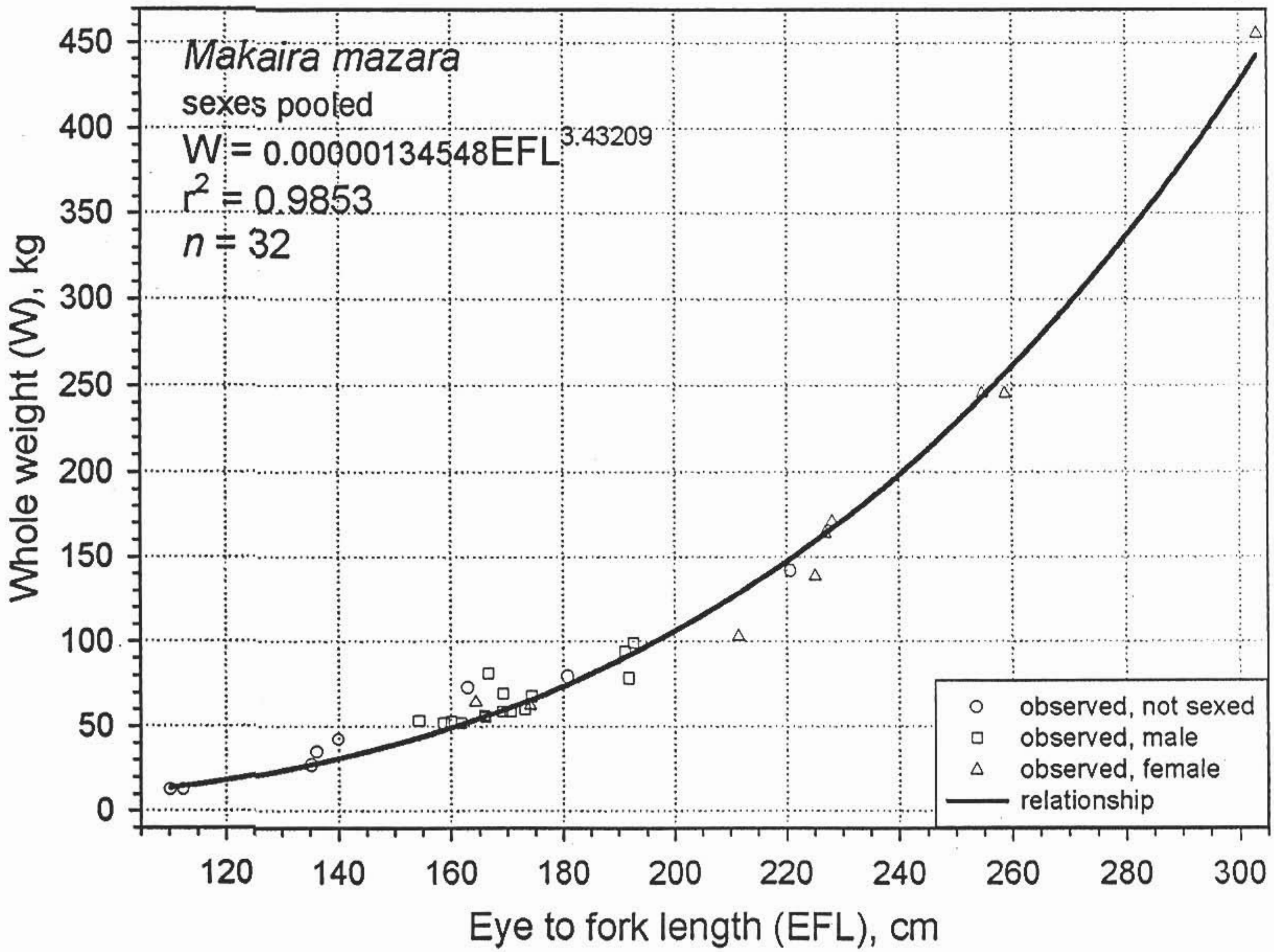


Figure 18. Weight-on-length relationship for Pacific blue marlin, *Makaira mazara*, from the equatorial and central North Pacific Ocean.

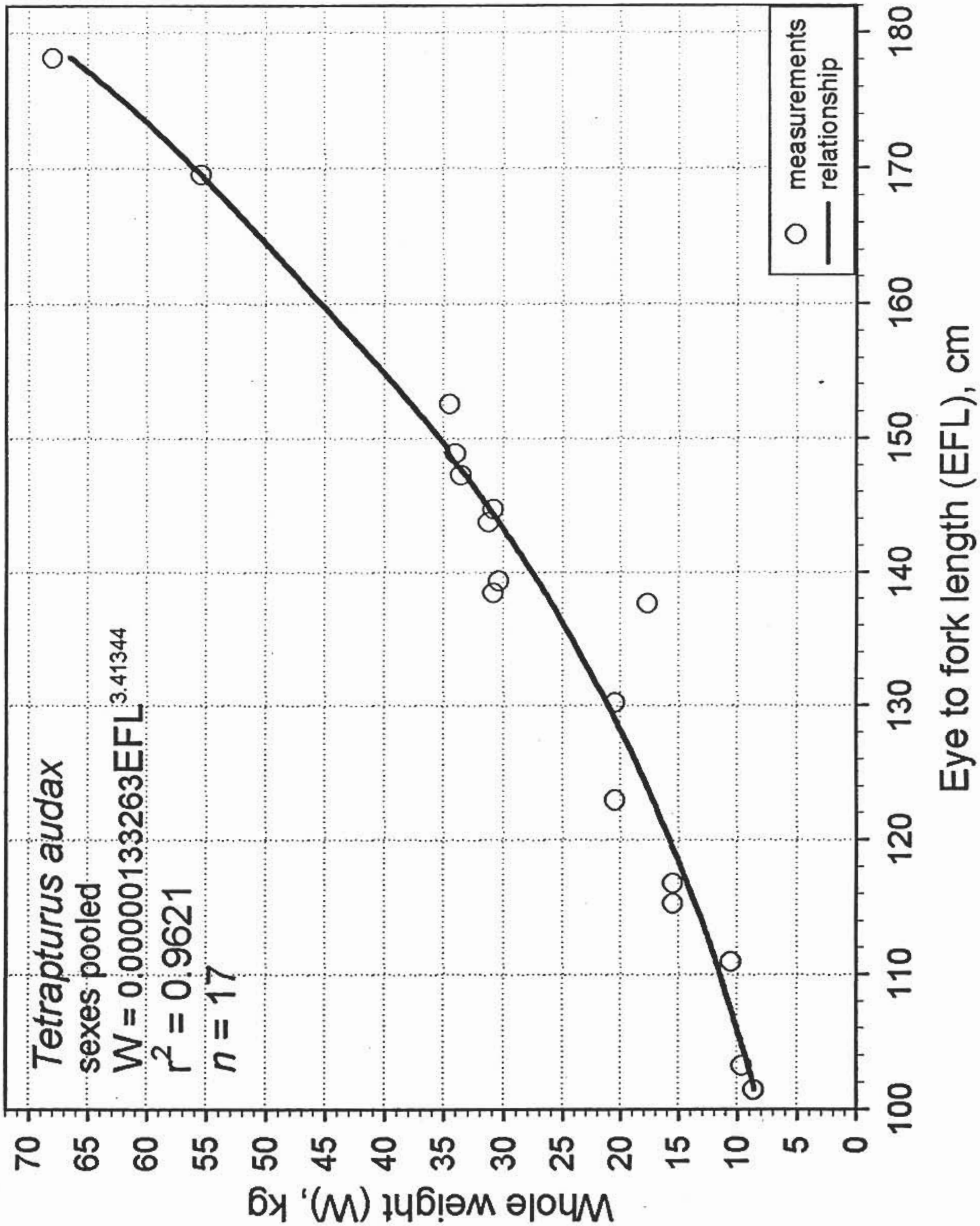


Figure 19. Weight-on-length relationship for striped marlin, *Tetrapturus audax*, from the central North Pacific Ocean.

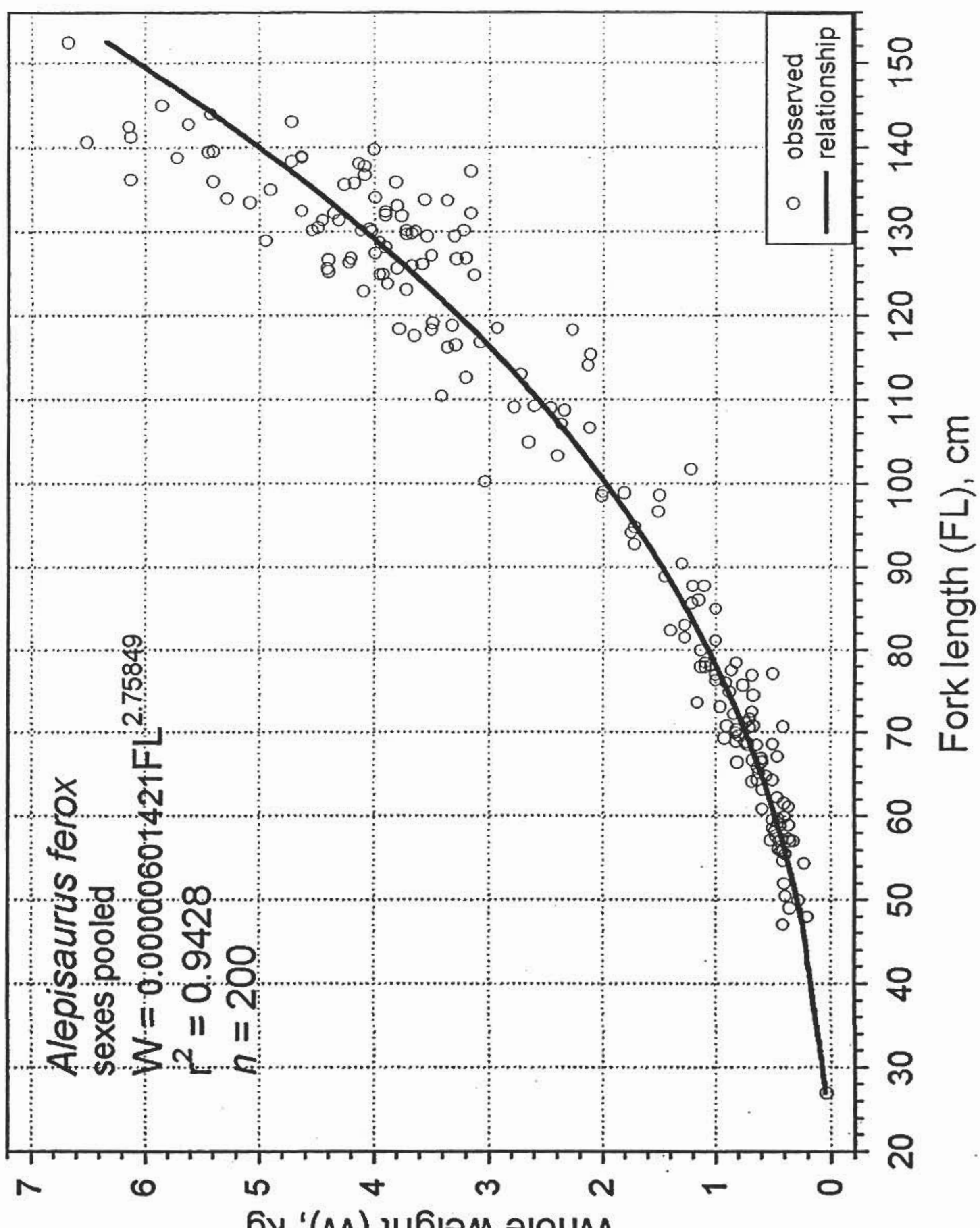
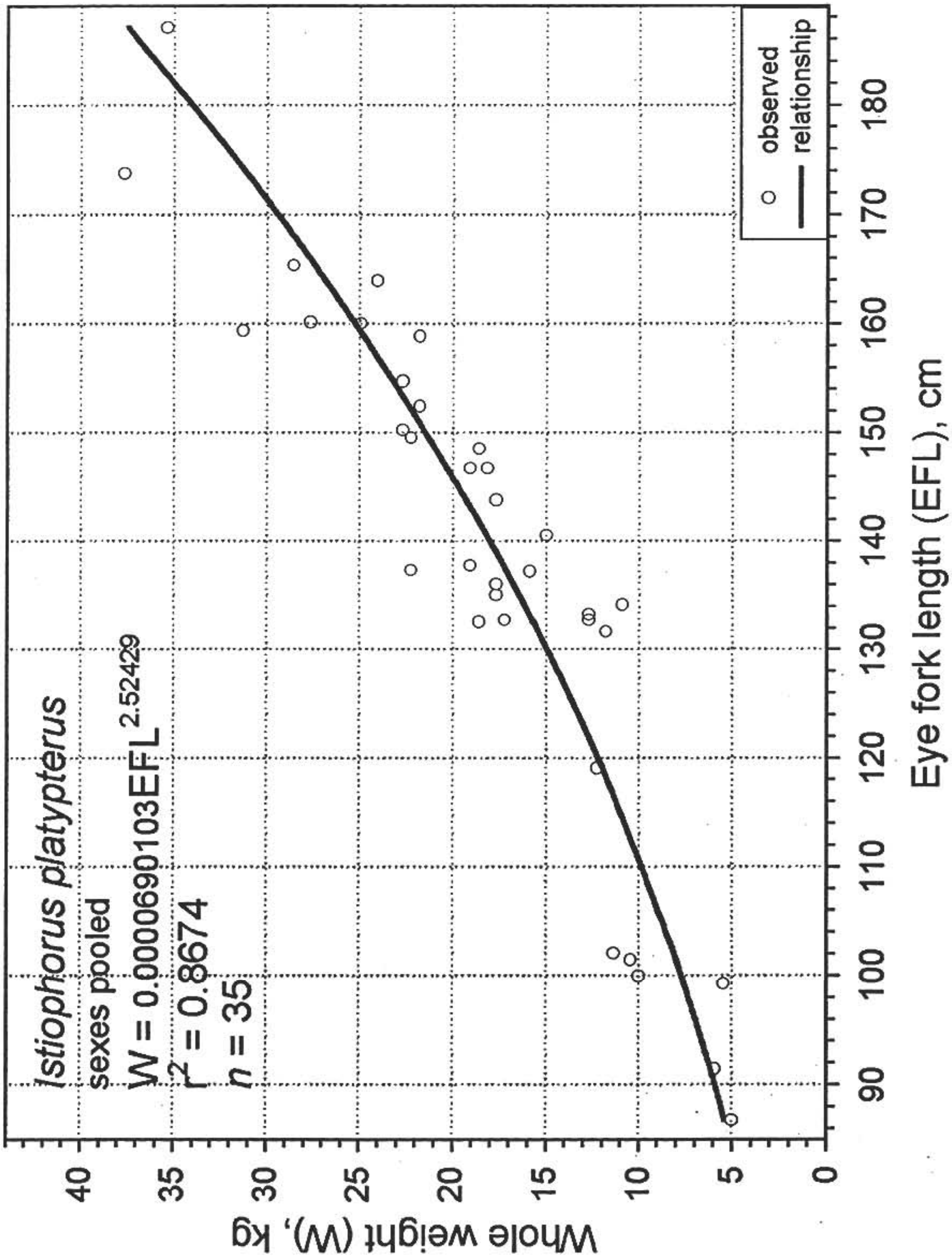


Figure 20. Weight-on-length relationship for longnose lancetfish, *Alepisaurus ferox*, from the central North Pacific Ocean.

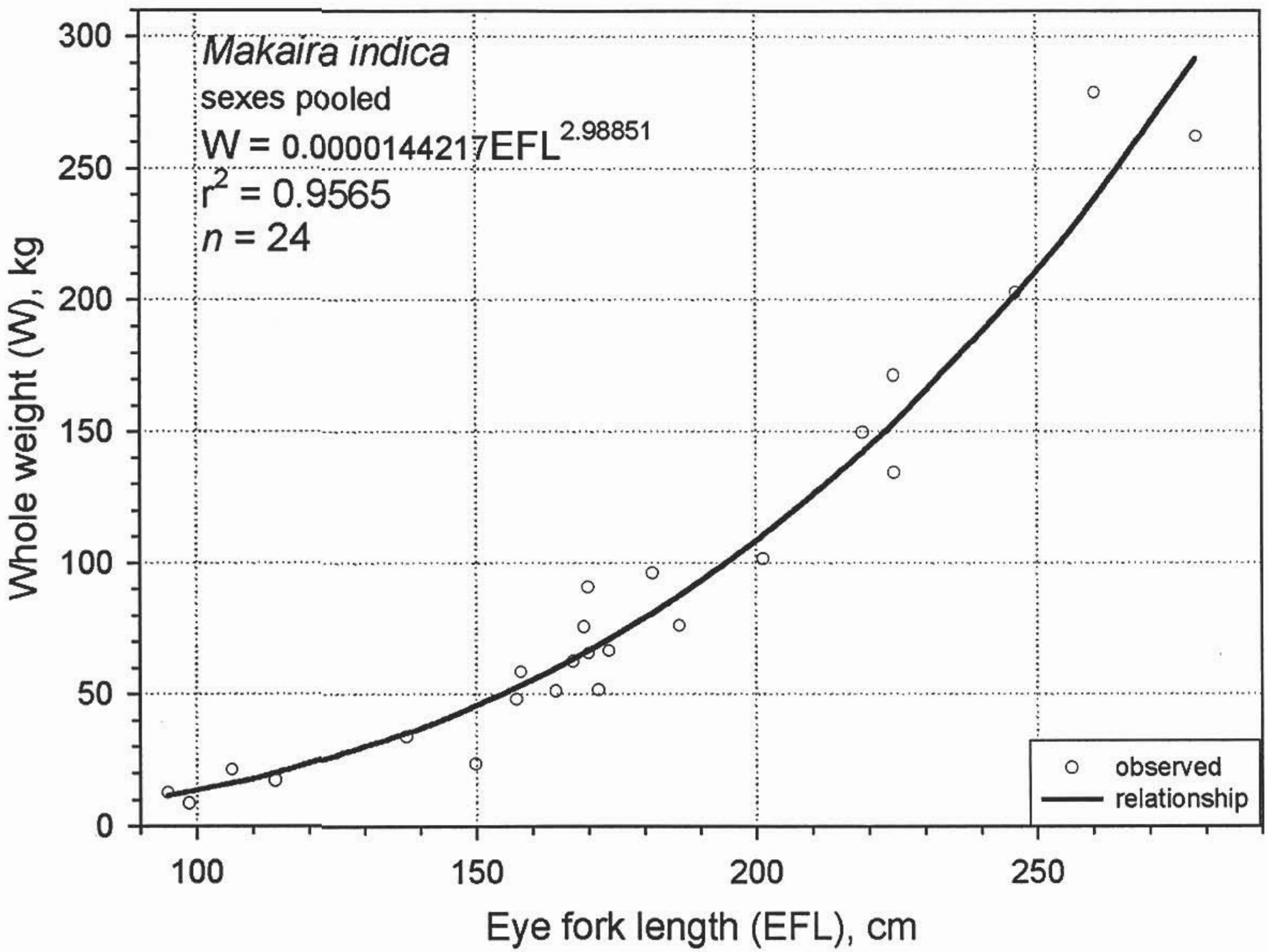
Appendix Table 1. Nonlinear eye to fork length (**EFL**)-on-whole weight minus bill weight (W) and whole weight minus bill weight-on-eye to fork length relationships for billfishes measured at the Honolulu fish auctions from 1967 to 1970. *n* = number of fish.

		Model $Y=aX^b$			Exponent		Constant		Range Weight (kg)		Range Length (cm)	
Specie	Relation	r^2	s.e.	*n*	***b***	s.e.	***a***	s.e.	Min.	Max	Min.	Max.
Istiophorus platypterus	W on EFL	0.867	2.8557	35	2.52429	0.174663	6.90103E-5	6.51256E-5	5.0	37.6	86.8	187.1
sexes pooled	EFL on W	0.871	8.45076	35	0.347166	0.0240131	51.4235	3.70449				
Makaira indica	W on EFL	0.956	15.5847	24	2.98851	0.131449	1.44217E-5	1.12758E-5	8.6	279.0	94.9	278.6
sexes pooled	EFL on W	0.954	10.3739	24	0.309442	0.0146699	46.9705	3.23132				
M. mazara	W on EFL	0.932	13.4462	154	3.30967	0.0565521	2.72228E-6	9.03003E-7	10.4	381.1	109.2	269.3
sexes pooled	EFL on W	0.929	8.18229	154	0.283377	0.0060683	52.0203	1.38183				
Tetrapturus angustirostris	W on EFL	0.511	2.54002	80	2.30582	0.246868	1.88756E-4	2.43721E-4	6.8	23.5	89.2	153.6
sexes pooled	EFL on W	0.531	7.32387	80	0.23701	0.0254209	70.8103	4.97914				
T. audax	W on EFL[a]	0.802	4.7532	1427					8.1	99.8	100.3	198.0
sexes pooled	EFL on W	0.840	6.36518	1427	0.300417	0.0036272	51.3506	0.67264				
females	EFL on W	0.846	6.25288	630	0.301733	0.00531588	50.9618	0.993232	6.8	99.8	89.1	198.0
males	EFL on W	0.721	6.5336	671	0.293434	0.00716759	52.8873	1.35947	8.1	80.3	99.2	183.5

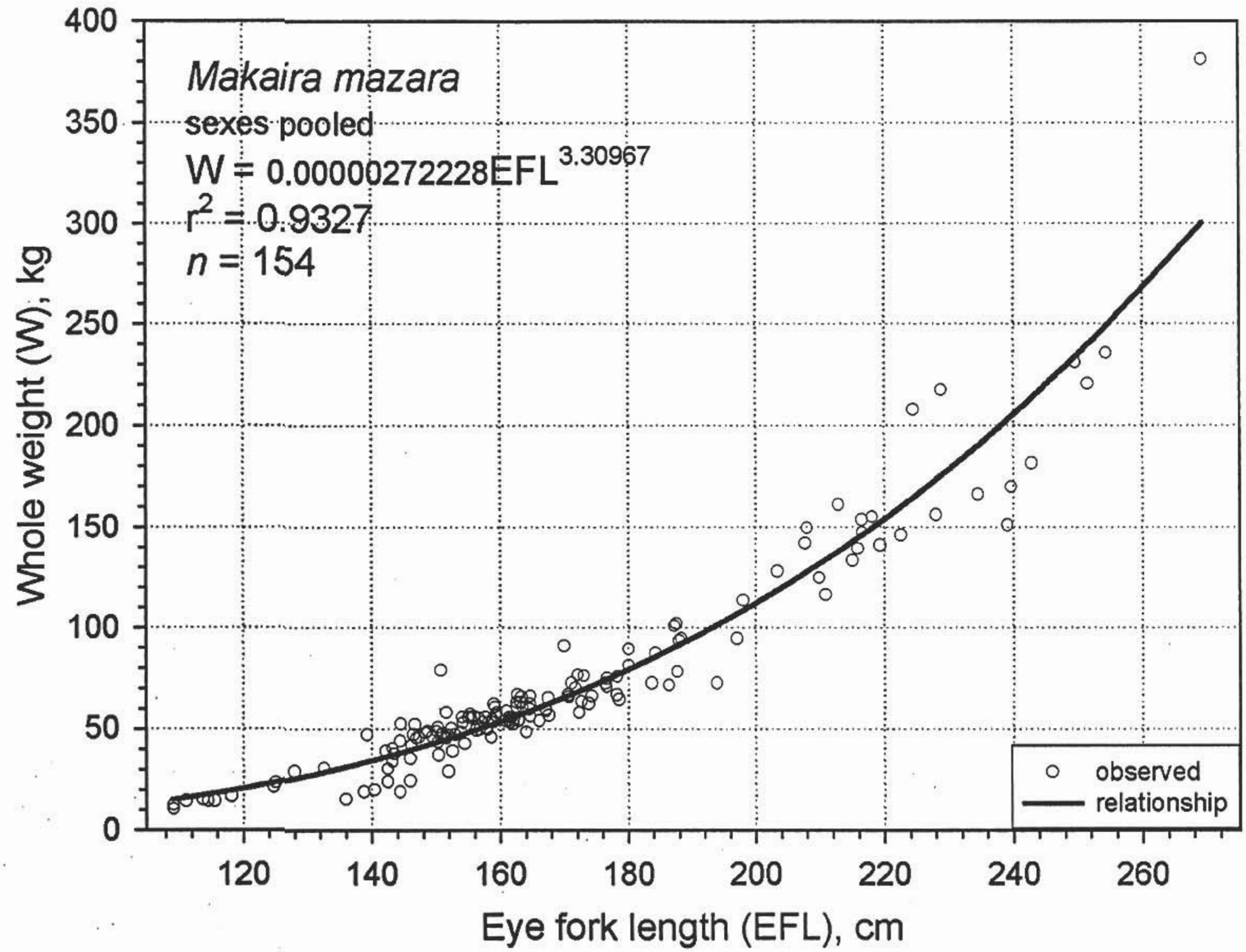
[a]full 2nd order polynomial equation: $W = -6.02372 + (-0.0647304EFL) + (0.0021165EFL^{2.01602})$.



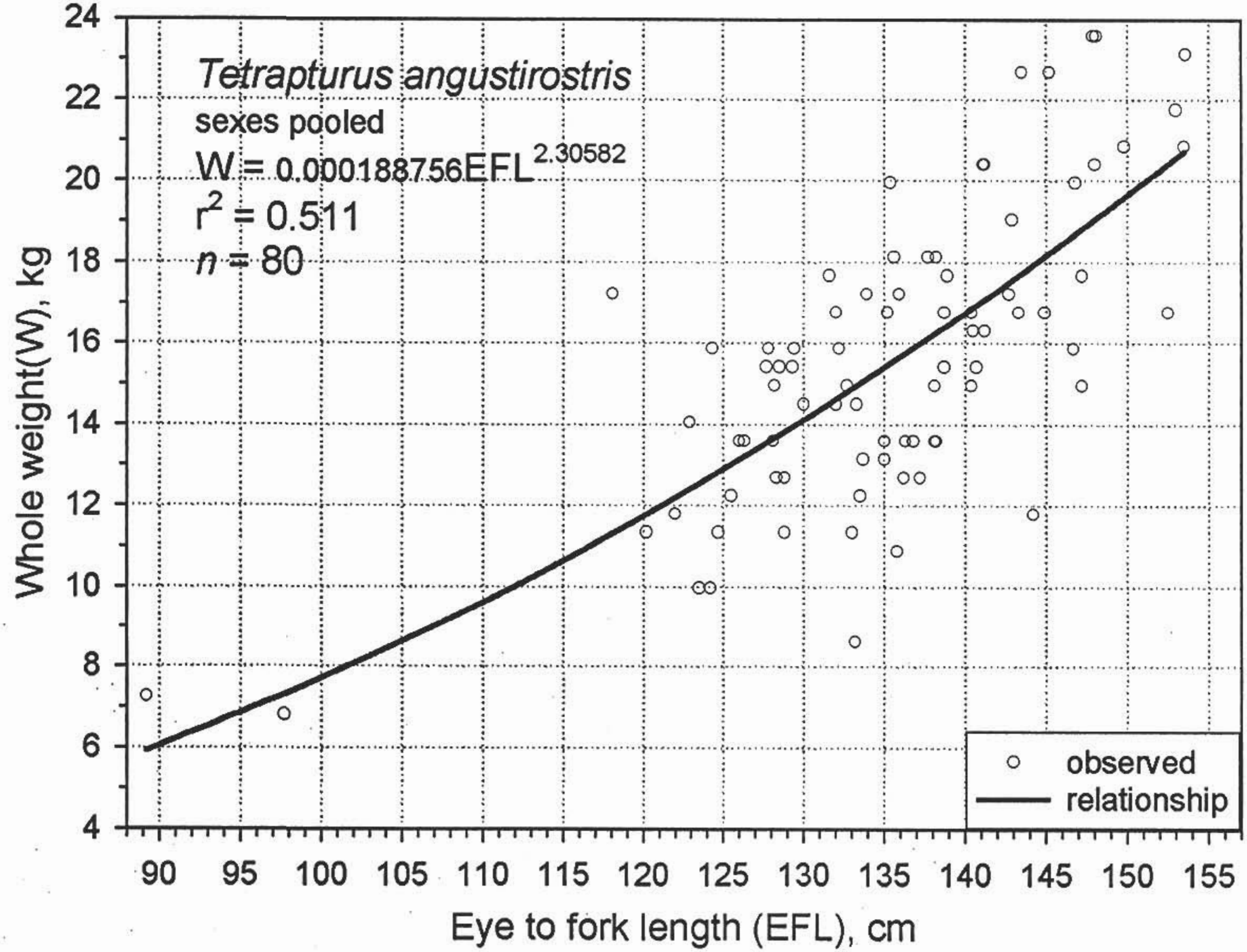
Appendix **Figure 1**. Weight-on-length relationship for sailfish, *Istiophorus platypterus*, measured at the Honolulu fish auctions, 1967-70.



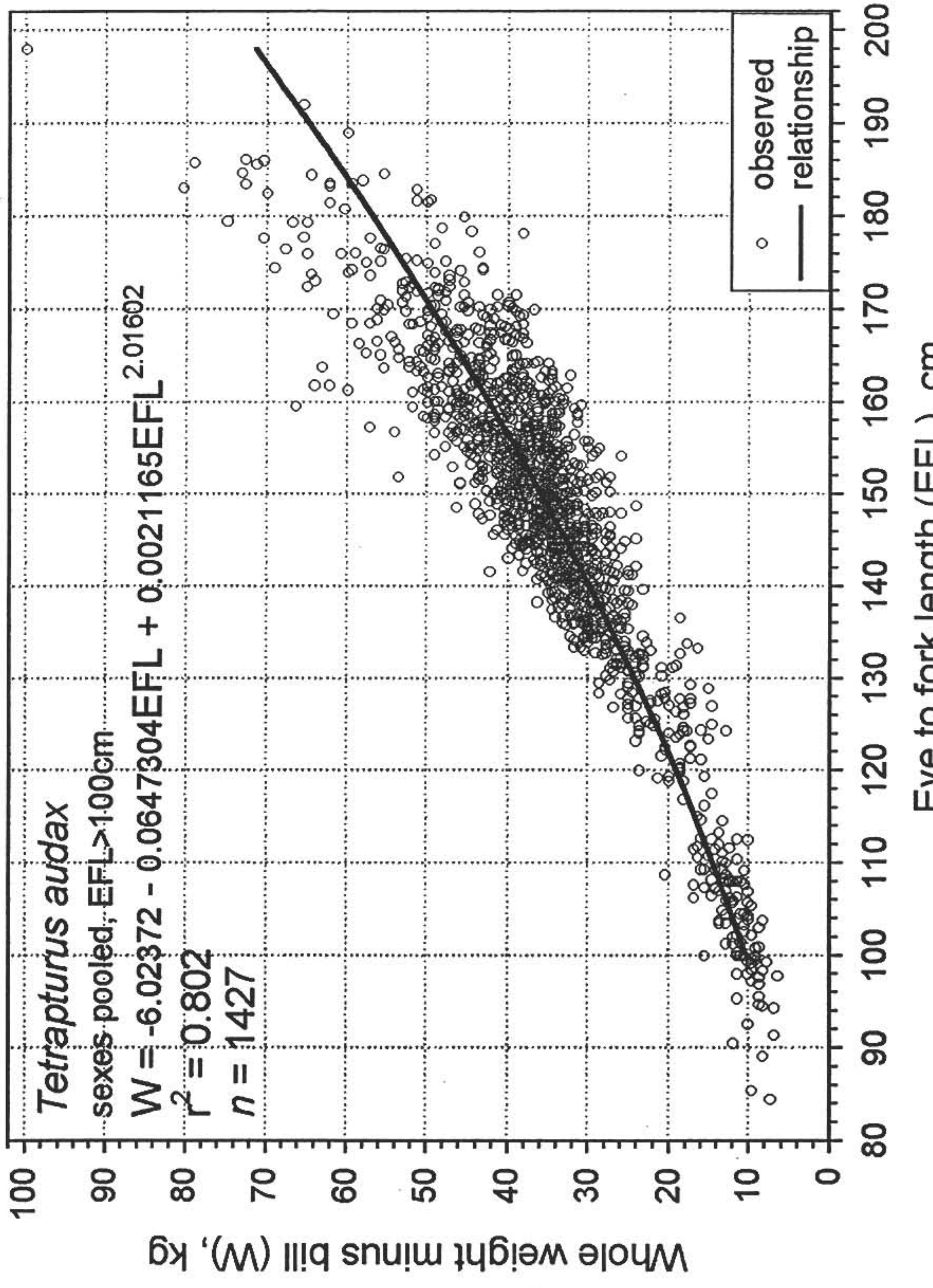
Appendix **Figure 2.** Weight-on-length relationship for black marlin, *Makaira indica*, measured at the Honolulu fish auctions, 1967-70.



Appendix **Figure 3.** Weight-on-length relationship for Pacific blue marlin, *Makaira mazara*, measured at the Honolulu fish auctions, 1967-70.



Appendix Figure 4. Weight-on-length relationship for short bill spearfish, *Tetrapturus angustirostris*, measured at the Honolulu fish auctions, 1967-70.



Appendix **Figure 5.** Weight-on-length relationship for striped marlin, *Tetrapturus audax*, measured at the Honolulu fish auctions, 1967-70.