NOAA Technical Memorandum NMFS

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AND GROWTH RELATIONSHIPS OF HAWAIIAN SNAPPER,
Pristipomoides filamentosus

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Abstract

Age-length and somatic growth interrelationships are redescribed for the Hawaiian pink snapper or "opakapaka," *Pristipomoides filamentosus*. This expanded characterization is based in part on new information for 0+ and I+ juveniles, together with previously published data for subadult-adult fish >20 cm fork length (FL). A total 92 juveniles and subadult-adults were aged using otoliths (sagittae); different techniques were used to estimate ages for the two groups of fish. Ages (in days) were estimated for 35 juveniles based on total counts of microincrements present in lateral view of the dorsal growth axis of ground whole mounts. The daily nature of microincrement counts was validated based on a tank experiment in which juveniles (16-24 cm FL) were injected with oxytetracycline and held for 37 days. Ages of 57 subadults-adults were previously estimated by analytical integration of increment widths. Estimated ages at length were fit to the von Bertalanffy growth function (VBGF); point estimates of VBGF parameters based on all 92 fish were more reasonable than prior estimates. Management implications of a reestimated VBGF growth coefficient ($K = 0.25 \cdot yr^{-1}$) are discussed relative to an earlier estimate ($K = 0.15 \cdot yr^{-1}$) used in prior simulations of sustainable yield.

INTRODUCTION

Bottomfisheries comprise a major component of all Hawaiian fisheries (Pooley, in press). The Hawaiiian pink snapper or "opakapaka," *Pristipomoides filamentosus*, contributed 19-36% by weight to the multispecies Northwestern Hawaiian Islands (NWHI) bottomfish landings during 1986-91 (Kawamoto, 1992)[1]. Opakapaka and other eteline snappers (Lutjanidae) dominate bottomfish catches throughout the tropical Pacific (Haight et al., in press).

Levels of sustainable yield of opakapaka in Hawaii have been modeled in part based on estimated rates of the von Bertalanffy growth function (VBGF) determined using subadult-adult fish (Ralston and Miyamoto, 1981, 1983). Much uncertainty regarding the age-length relationship of adult opakapaka exists because of the diverse techniques that have been used to age adult fish (Uchiyama and Tagami, 1984; Ralston and Miyamoto, 1981, 1983; Radtke, 1987; Williams and Smith, unpubl. manuscr.). Also, prior VBGF parameterizations have been limited to fish spanning the first 30-75% (25-60 cm fork length, FL) of the length distribution because large adults (>60 cm FL) are difficult to age (Ralston and Miyamoto, 1983) and because specimens <20 cm FL have become available only after the recent discovery of an abundant source of juveniles (Parrish, 1989).

Counts of microincrements on otoliths are now an established means of estimating the ages of tropical fishes, contingent upon validation of the daily nature of the microincrements for the particular population and life stage (Brothers, 1980; 1982;,Beamish and McFarlane, 1983; Jones, 1986; Geffen, 1992). Ralston and Miyamoto (1983) validated the daily nature of microincrements for subadult opakapaka 30-34 cm FL; however, no data were then available for small juvenile-sized fish. One of the objectives of this paper is to extend the validation of microincrements on otoliths of opakapaka to include small juvenile fish. With the added confidence of this validation, we expand an existing characterization of the age-length and growth relations of opakapaka with new data for age 0+ (young-of-year, YOY) and age I+ juveniles.

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[1]Kawamoto, K.E. 1992. Northwestern Hawaiian Islands Bottomfish Fishery 1991. Admin. Rep. H-92-12, Honolulu Lab., NMFS Southwest Fish. Sci. Cent., 20 p.

METHODS

Fish Collections and Processing

Specimens were obtained from several sources: large fish (>20 cm FL) were provided by commercial fishermen and fishery-independent research cruises throughout the main Hawaiian Islands (MHI) and the NWHI (Ralston, 1981; Ralston and Miyamoto, 1983).

YOY and I+ juvenile fish were collected by bottom trawl (Ellis et al., 1992)[2] off Kaneohe Bay, windward Oahu, during December 1990, with additional specimens collected by hook-and-line during March, July, and September-November 1990.

Fork Length (cm) was measured for frozen-thawed specimens of the entire available size range.

Otolith Processing

Otoliths (sagittae) were dissected out of frozen-thawed fish; usually both members of an otolith pair were stored refrozen in water (to avoid fungal growth) until preparation. Otoliths from YOY and I+ juveniles were prepared differently from those of larger fish. After drying, either the right or left member of the otolith pair (random choice) was mounted lateral surface up in epoxy resin. The medial surface of whole mount was ground manually with 400 grit paper until exposed, then further ground using 1200 grit paper until the focus emerged. Preparations were polished with 0.3 μm alumina-silica powder. Specimens were ground and polished until microincrements along the growth axis between the focus and the dorsal dome became continuously distinct when viewed with a compound binocular microscope at 400X magnification using transmitted light. The dorsal growth axis was chosen because increments in juvenile otoliths were most frequently continuous in this region, even though increment spacing is generally greater along the longer postrostral axis (Ralston and Miyamoto, 1983). It was unnecessary to clear or etch (Ralston and Miyamoto, 1983; Ralston and Williams, 1988) the otoliths of these small juveniles. Preparation of the sagittal otoliths of subadult-adult fish is described by Ralston and Miyamoto (1981, 1983).

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[2]Ellis, D.M., E.E. DeMartini, and R.B. Moffitt. 1992. Bottom trawl catches of juvenile opakapaka, _Pristipomoides filamentosus_ (F. Lutjanidae), and associated fishes, _Townsend Cromwell_ cruise TC-90-10 1990. Admin. Rep. H-92-03, Honolulu Lab., NMFS Southwest Fish. Sci. Cent., 33 p.

Age Estimates

Ages of young and old fish were estimated using two different methods that were suitable for the respective size and age group. Ages (in days) of 35 juvenile fish were estimated based on total counts of microincrements apparent along the entire dorsal growth axis. Five blind replicate counts were made for each specimen, and the mean of these five counts was used as the best estimate of age. Ages (in years) estimated for 57 subadult-adult fish using Ralston and Miyamoto's (1983) increment width integration method were reexpressed as ages in days for this reanalysis.

Fitting the Growth Curve

The relation between age and length was described by the VBGF, as previously done by Ralston and Miyamoto (1983), using the Proc NLIN procedure of the Statistical Analysis System (SAS, Inc., 1987).

Microincrement Validation

Eleven juveniles, 16-24 cm FL, collected by hook-and-line and baited funnel trap off Kaneohe Bay by the NOAA ship *Townsend Cromwell* during August 18-20 1992, were held in 5000-gal live wells aboard ship for 4-6 days. The fish did not feed while aboard ship. Upon return to port on August 24, the fish were transferred to the Honolulu Laboratory's Kewalo Research Facility, where they were held in outdoor, circular 4000-gal flowing seawater tanks at 24-25°C under a natural day:night cycle. Fish were fed a daily ration of strips of squid (*Loligo* sp.) at 5-10% body weight. Some fish began feeding on August 27, and all fish were feeding by August 28. On September 2, each fish was hand-netted and placed in a wet Ziploc® plastic bag to minimize handling trauma. Its length was measured (cm FL) with calipers, and needle-nosed side-cutters were used to sever 1-2 dorsal fin spines or rays (Welch and Mills, 1981), thereby creating a unique combination of unobtrusive scars by which the fish was individually recognizable. The weight of each fish was estimated from a length-weight key (Moffitt and Parrish, unpubl. manuscr.) and each fish was intraperitoneally injected (using a #18 needle) with 0.3-0.8 ml (30 mg·kg^{-1} for fish 75-250 g wet body weight) of oxytetracycline ("OTC", Liquimycin 100, diluted 10 times), and returned to the tank. After 2-4 days, fish had resumed feeding on squid strips, augmented by a ground mixture of nehu anchovy (*Encrasicholina purpurea*), squid, and vitamins. One of the 11 fish disappeared from the tank. Another test fish became moribund and was sacrificed after only 14 days. On October 9, the 9 remaining survivors were sacrificed, FL remeasured, and weighed. Fish were then frozen whole, thawed fish were remeasured, and otoliths extracted and stored in darkened vials until examination.

Validation of Daily Growth Checks

All 10 surviving fish incorporated fluorescent marks on otolith sagittae; these OTC marks appeared as several increment-wide, internal bands on whole otoliths viewed under ultraviolet (UV) light in a darkened room. The OTC mark on otoliths of the moribund, early-sacrificed fish was atypically near the growing edge of the otolith, and this specimen was excluded from analysis. For each of the remaining nine fish, location of the proximal edge of the OTC mark on either the right or left otolith was noted under UV light, and increments visible within the dorsal growth axis (distal to the proximal edge of the OTC mark) enumerated using white light. Otoliths of the 9 tank-test fish were otherwise prepared exactly as were the otoliths of the 35 wild fish used to characterize the juvenile growth curve.

Increments were not continuously distinct distal to the OTC mark on otoliths of test fish. The total (including indistinct) number of increments formed after OTC marking therefore was estimated in the following manner: for each of 3-7 (median and mode = 4) readable, tank-Test ("test") segments per otolith, segment width was measured along the dorsal growth axis, using a calibrated ocular micrometer. Also measured were the distances between the segment's midpoint and proximal edge of the OTC mark, and between the segment's midpoint and the otolith edge. The number of included increments was counted (median = 6), and a mean increment width calculated. To provide estimates of natural ("pre-test") otolith growth, mean increment widths were also estimated for regions internal to, and terminating no closer than about 10 increments distance from, the OTC-marked regions of otolith. Each test otolith segment was matched with one equally broad (median = 6 increments) pre-test segment and the mean increment width of the latter similarly estimated.

RESULTS

Microincrement Validation

The amount of growth along the dorsal axis of the otolith (as mean distance between OTC mark and otolith edge) differed (coefficient of varation (CV) = $(SD/\bar{x}) \cdot 100 = 20\%$) among the 9 test fish ($F_{8,30} = 6.5$; $P<0.001$). Growth along the dorsal axis was related (but weakly, due to few data and low power) to observed increase in body length of the respective fish (Spearman's $r_s = 0.56$; $P = 0.12$). Mean increment width, however, was indistinguishable among the test fish ($F_{8,29} = 0.82$; $P = 0.59$). The frequency distribution of segment positions (fractional distance along the dorsal axis) also did not differ for fish whose otolith growth was above and below the median for all 9 fish (Smirnov 2-sample test; $\chi^2 = 0.33$, 2 df, $P>0.8$; Conover, 1980). And, for all 39 readable segments on the 9 otoliths, increment width was unrelated to position of the

segment along the dorsal growth axis (r^2 = 0.03; P = 0.25). We therefore pooled all increment readings of the 9 fish for further analysis, and estimated a mean number of increments using all of the readings. We thereby estimated that test fish on average laid down 38 microincrements during the 37-day experiment.

The same data were reanalyzed to evaluate the possibility of slower growth early in the experiment, before all fish had resumed feeding. The number of microincrements laid down following OTC injection was reestimated as 36, assuming two phases with slower growth during the first 4 days following injection. If an inflection in growth rate occurred at 2 or at 6, rather than 4, days following injection, the number of estimated increments remains virtually the same (37 and 36, respectively).

That growth along the dorsal otolith axis was representative and constant during the experiment is corroborated by a comparison of increment widths between matched test and pre-test otolith segments. The mean increment widths of matched-pairs of segments were similar (delta-bar = 0.18 μm; paired-t = 0.96; 0.4>P>0.3) over the entire readable spectrum of the dorsal growth axis. On average, test and pre-test increment widths differed only by 3% (mean widths of 3.07 μm and 3.17 μm for test and pre-test segments, respectively). Otolith growth thus was constant during at least the last 85-95% of the experiment.

Growth of Experimental Fish

During the 37-day experiment, the 7 fastest-growing survivors increased in body length a mean 2.1 ± 0.4 (±SD) cm or about 11% (from 19.6 to 21.7 cm FL), and added an estimated mean 56% total wet body weight. The average rate of increase in body length was about 0.5 mm·day^{-1}.

Juvenile Fish Ages

Estimated ages of the 35 juveniles ranged from 134 to 408 days, with the smallest (8.4 cm FL) an estimated 160 days and the largest (19.8 cm) an estimated 408 days. The mean CV of the 5 replicate counts was 7% for the 35 fish.

Combined Juvenile-Adult Growth Curve

A VBGF satisfactorily describes the growth trajectory for small and large fish combined (Table 1; Fig. 1). Viewed at the expanded scale of Fig. 2, the rate of growth of 8-20 cm FL juveniles appears to weakly decelerate with increasing size and age, but without any inflection (abrupt change in rate) at any particular body size.

DISCUSSION

Laboratory Validation Experiment

Our laboratory results for small juvenile opakapaka extend those of Ralston and Miyamoto (1981, 1983) for larger juvenile and subadult fish. The average width of microincrements measured distally along the postrostrum of otoliths of older I+ subadults was 4.5 μm (Ralston and Miyamoto, 1983, Fig. 6; S. Ralston, unpubl.data). The average width of microincrements along the distal dorsal axis of otoliths was about 3.1 μm for younger I+ juveniles (this study). Thus the widths of microincrements, each independently validated as daily, agree for our smaller juveniles and Ralston and Miyamoto's (1983) larger juveniles, after allowance for the approximately three-fourths greater mean distance between focus and otolith edge (and coorespondingly greater mean width of increments) measured along the postrostral, as opposed to the dorsal, axis (Ralston and Miyamoto, 1983). These observations, together with the indistinguishability of increment spacing before and after OTC treatment of our test fish, proves beyond reasonable doubt that the observed microincrements are formed daily, at least for older YOY and I+ juvenile (this study) and subadult (Ralston and Miyamoto, 1983) *P. filamentosus.*

Bertalanffy Growth

Addition of the age-length data for small fish substantively improves upon Ralston and Miyamoto's (1983) VBGF fit using data for the larger fish only. Reestimates of the VBGF parameters using data for all of the 92 specimens now available seem more accurate for several reasons. First of all, our reestimates of the VBGF growth coefficient compare favorably with independent estimates based on length frequency (ELEFAN) analysis of juvenile fish ($K = 0.21 \cdot yr^{-1}$; Moffitt and Parrish, unpubl. manuscr.). Juvenile fish in the OTC experiment laid down daily increments while they increased in body length and weight at rates that were within an estimated 10-15% of those observed from modal size progressions in field collections (Moffitt and Parrish, unpubl. manuscr.). At the mean rate of growth observed for fish in the OTC tank experiment ($0.5 \text{ mm} \cdot day^{-1}$), a body length of about 18 cm FL would be attained by age I, a value similar to that observed by Moffitt and Parrish (unpubl. manuscr.) in their modal size progression analysis. Second, typical VBGF growth rate estimates for later-stage *P. filamentosus* elsewhere in the tropical Pacific report K values that fall between 0.2 and 0.3 (e.g., Brouard and Grandperrin, 1985). Third, it should be generally true that VBGF reparameterizations increase in accuracy when age ranges are expanded to include younger fish (Hirschhorn, 1974).

The combined juvenile-adult curve fit also is more precise, and only partly because of the larger sample size. The juvenile age-length data have relatively minor scatter; perhaps more importantly, data spanning a greater age range provide a better resolution of curvature (Hirschhorn, 1974). Ralston and Miyamoto's (1983, Table 2) standard errors for K, t_0, and L_∞ (the latter freely fitted) using the original 57 subadults-adults were 14%, 37%, and 42% of the respective estimate, compared to our values of 11%, 38%, and 5%, respectively.

The lack of observed inflection in growth rate within the age-length curve of older YOY and I+ fish indicates that the growth of post-settlement juveniles is not better described by an alternative (e.g., Gompertz) growth model. This latter suggestion of Ralston and Williams (1988), however, should be appropriate for age records that span larval substages or a pelagic-benthic transition in which abrupt changes in growth rates reflect major developmental phenomena such as flexion or settlement. Any future extension of the growth curve to include larvae or pelagic juveniles should consider other, perhaps mixed, growth models that account for likely inflections in growth rates.

The increasing variance of age estimates for large adult opakapaka remains an unresolved problem. That estimated ages of large opakapaka vary in proportion to body size and age undoubtedly reflects both greater natural variability and the larger sampling error associated with ageing older fish (Ralston and Miyamoto, 1983).

More accurate and precise enumeration of microincrements on otoliths of large adult opakapaka, and large-bodied, long-lived reef fishes in general, often requires resolution beyond that possible using light microscopes. Morales-Nin and Ralston (1990) and Sudekum et al. (1991) provide good examples of electron microscopic studies that enumerate microincrements too dense to be resolved by light microscopy. Whether such costly, time-consuming studies are warranted depends on how important it is, in each particular application, to better describe the age-length relationship of large, adult fish.

Management Implications

Historically, estimation of yield-per-recruit (Y/R) for opakapaka and other Hawaiian bottomfishes has been based on the ratio of M/K, where M (natural mortality) has been estimated from K (Ralston, 1987). Thus, the larger values of K (estimated in this paper) would not effect future reestimates of Y/R. The ratio F/M also has been used as an index of exploitation, however, with allowable upper bounds of F = 2M and M = 2K (Polovina, 1987). Larger K values thus imply larger M and F_{opt} values and higher upper bounds on levels of sustainable yield.

Most recently, VBGF parameters have been used in the IMMAGE model of Somerton and Kobayashi (1992) to estimate Spawning Potential Ratio (SPR, the ratio of currently exploited to virgin spawning biomass) for *P. filamentosus* in Hawaii (Kobayashi, unpubl.). An age-structured, length-expressed simulation model (Kobayashi, 1993)[3], based on the IMMAGE model, also has input VBGF K and t_0 parameters to estimate sustainable yields of opakapaka and other Hawaiian bottomfishes. Point estimates of $K = 0.15 \cdot yr^{-1}$ and $t_0 = -1.67$ yr have been used in the latter simulations for opakapaka, based on the constrained ($L_\infty = L_{max} = 78$ cm FL) VBGF model fit of Ralston and Miyamoto (1983, Table 2). Our reestimates herein suggest that future simulations inputting larger K and smaller t_0 values might provide more accurate estimates of yield for *P. filamentosus* in Hawaii. The latter possibility clearly deserves further study.

ACKNOWLEDGMENTS

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Table 1. Von Bertalanffy growth function parameters for 35 0+
          and I+ juveniles, plus the 57 subadults-adults
          previously described by Ralston and Miyamoto (1983).

Parameter	Estimate	SE	95% CI
K (1/yr)	0.25	0.027	0.20 to 0.31
t_o (yr)	-0.22	0.083	-0.39 to -0.06
L_∞ (FL, cm)	70.4	3.28	63.9 to 76.9

$$L_t = 704\{1 - e^{-0.25(t+0.22)}\}$$

$$n = 92$$
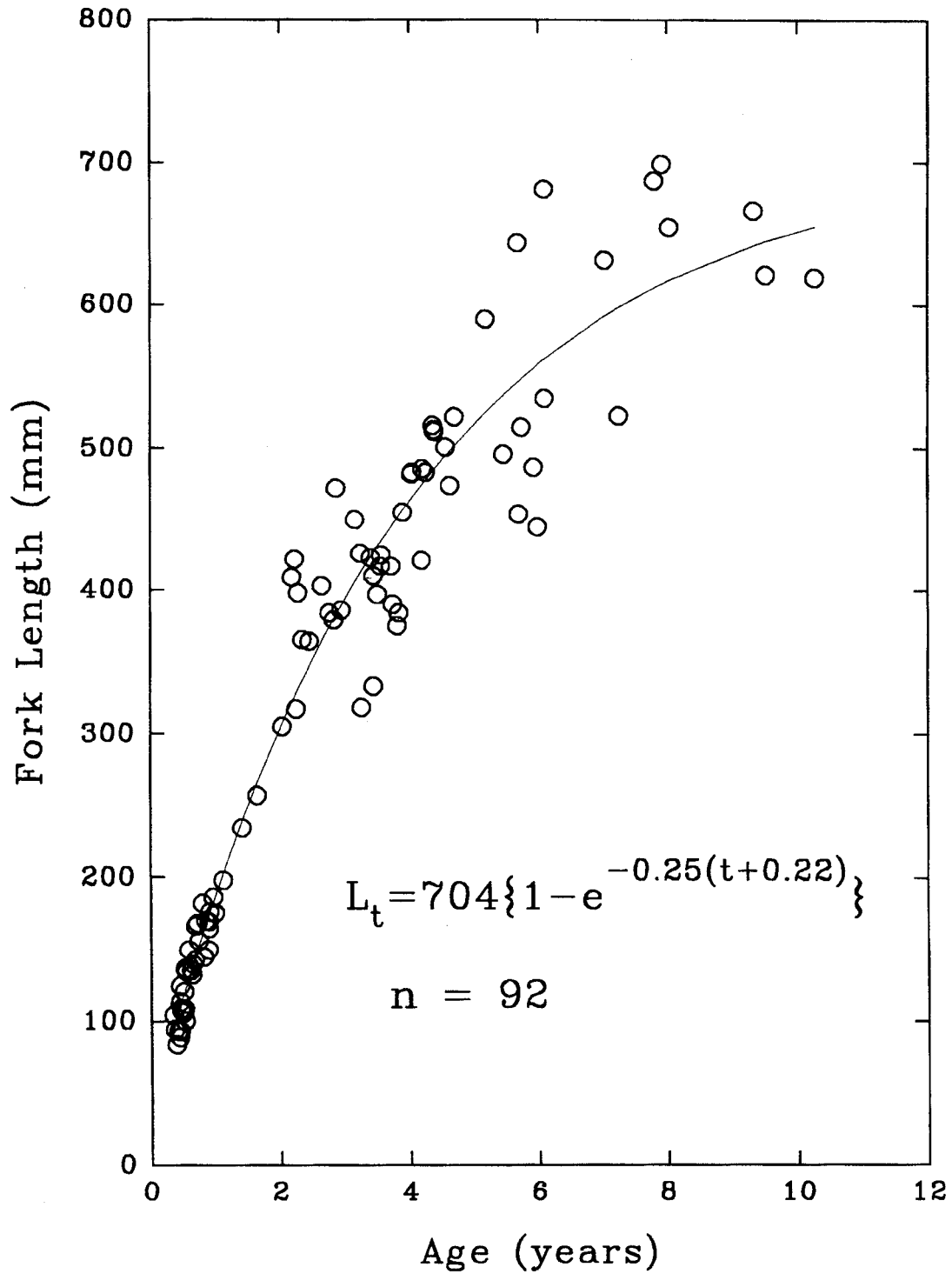
Figure 1.   Observed (hollow circles) and predicted (solid line) lengths-at-age for 35 YOY and I+ juveniles and 57 subadult-small adult opakapaka (*Pristipomoides filamentosus*), based on the von Bertalanffy growth model.
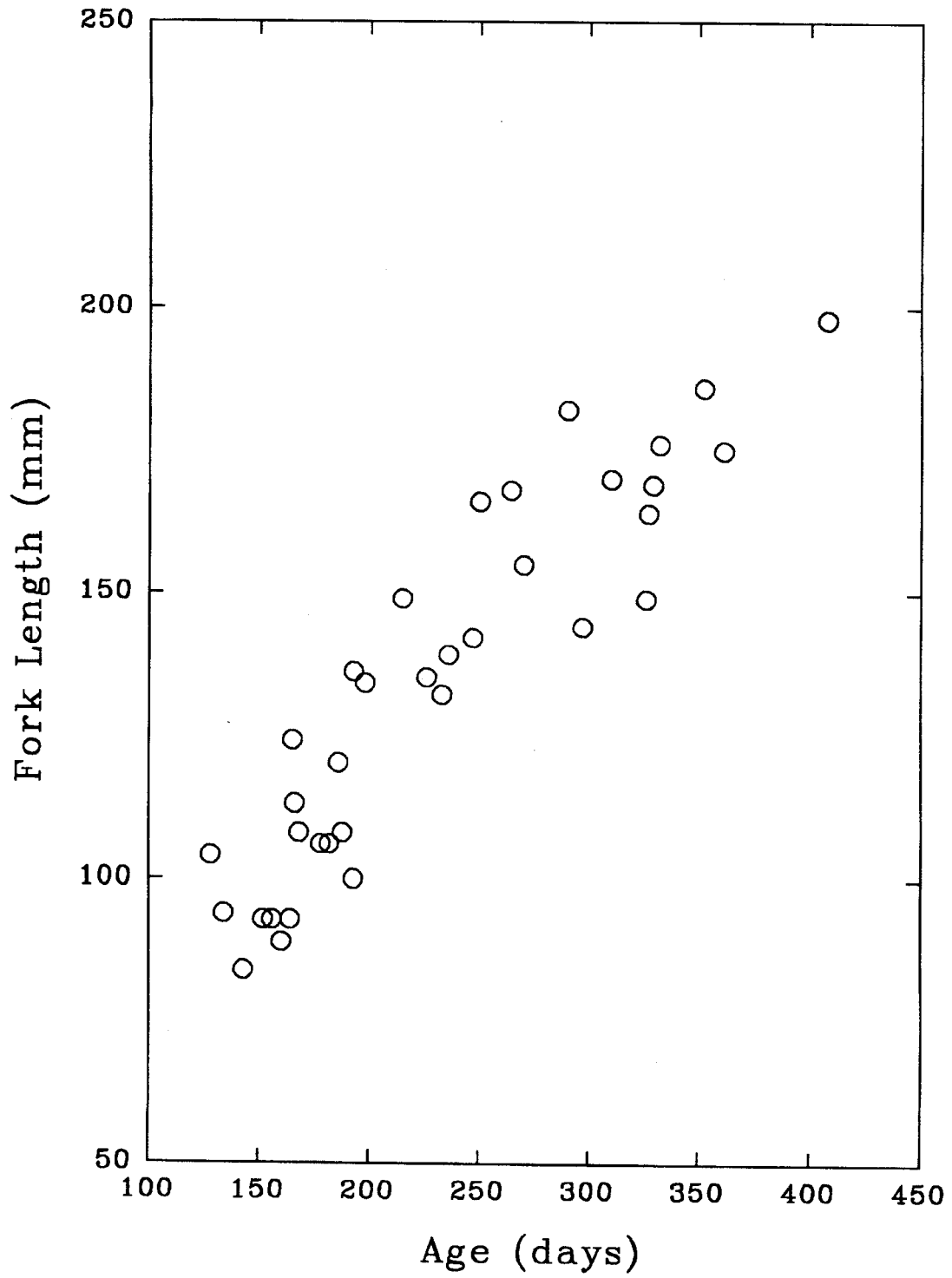
Figure 2.   Scatterplot of observed length-at-age for 35 YOY and
            I+ juvenile opakapaka (*Pristipomoides filamentosus*).

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