weight might cause allometry. Zweifel and Lasker (1976) briefly considered the length-weight relation in terms of a modified Gompertz-type relation and noted overestimation problems in extrapolation at the largest sizes.

Length-weight relations have merit, but their usefulness is greatly enhanced when combined with other studies, particularly those on age. Length-weight by itself does not necessarily imply rate of change because of the potential influence the environment may have on changing growth with time. However, when correlated with age and compensated for change in rate due to biotic and abiotic influences, length-weight studies can be an important component in estimating growth, survival, and population production.

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Literature Cited

BECKMAN, W. C.
1948. The length-weight relationship, factors for conversions between standard and total lengths, and coefficients of condition for seven Michigan fishes. Trans. Am. Fish. Soc. 75:237-256.
BLAXTER, J. H. S.
1969. Development: eggs and larvae. *In* W. S. Hoar and D. J. Randall (editors), Fish physiology, Vol. 3, p. 177-252. Academic Press, N.Y.
EHRLICH, K. F., J. H. S. BLAXTER, AND R. PEMBERTON.
1976. Morphological and histological changes during the growth and starvation of herring and plaice larvae. Mar. Biol. (Berl.) 35:105-118.
FARRIS, D. A.
1959. A change in the early growth rates of four larval marine fishes. Limnol. Oceanogr. 4:29-36.
HOUDE, E. D.
1974. Effects of temperature and delayed feeding on growth and survival of larvae of three species of subtropical marine fishes. Mar. Biol. (Berl.) 26:271-285.
LASKER, R.
1975. Field criteria for survival of anchovy larvae: The relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull., U.S. 73:453-462.
LASKER, R., H. M. FEDER, G. H. THEILACKER, AND R. C. MAY.
1970. Feeding, growth, and survival of *Engraulis mordax* larvae reared in the laboratory. Mar. Biol. (Berl.) 5:345-353.
LAURENCE, G. C.
1974. Growth and survival of haddock *Melanogrammus aeglefinus* larvae in relation to planktonic prey concentration. J. Fish. Res. Board Can. 31:1415-1419.
1975. Laboratory growth and metabolism of the winter flounder *Pseudopleuronectes americanus* from hatching through metamorphosis at three temperatures. Mar. Biol. (Berl.) 32:223-229.
1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus*, larvae during the period from hatching to metamorphosis. Fish. Bull., U.S. 75:529-546.
In press. Comparative growth, respiration and delayed feeding abilities of larval cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as influenced by temperature during laboratory studies. Mar. Biol. (Berl.)
MARSHALL, S. M., A. G. NICHOLLS, AND A. P. ORR.
1937. On the growth and feeding of the larval and post-larval stages of the Clyde herring. J. Mar. Biol. Assoc. U.K. 22:245-268.
RICKER, W. E.
1973. Linear regressions in fishery research. J. Fish. Res. Board Can. 30:409-434.
ROUNSEFELL, G. A., AND W. H. EVERHART.
1953. Fishery science: its methods and applications. John Wiley and Sons Inc., N.Y., 444 p.
SMIGIELSKI, A. S.
1975a. Hormone-induced spawnings of the summer flounder and rearing of the larvae in the laboratory. Prog. Fish-Cult. 37:3-8.
1975b. Hormonal-induced ovulation of the winter flounder, *Pseudopleuronectes americanus*. Fish. Bull., U.S. 73:431-438.
STEPIEN, W. P., JR.
1976. Feeding of laboratory-reared larvae of the sea bream *Archosargus rhomboidalis* (Sparidae). Mar. Biol. (Berl.) 38:1-16.
ZWEIFEL, J. R., AND R. LASKER.
1976. Prehatch and posthatch growth of fishes—a general model. Fish. Bull., U.S. 74:609-621.

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EFFECT OF THERMAL INCREASES OF SHORT DURATION ON SURVIVAL OF *EUPHAUSIA PACIFICA*

Euphausiids are an important source of food for many valuable species of fish including herring, cod, pollock, and salmon. Cooney (1971) reported that *Euphausia pacifica* was the most abundant species associated with the diffuse scattering layer at all locations in Puget Sound, Wash. He found that during the day euphausiids are most abundant between depths of 50 and 100 m and that at night most of the population migrates into the upper 50 m. Cooney's findings indicate that great numbers of euphausiids could be drawn through the condenser cooling systems of thermal nuclear power plants where they would encounter a sizable thermal shock.

Zooplankton entrained in a power plant cooling system located in a saltwater environment could be subjected to an average temperature increase ranging from 12° to 16°C (Coutant 1970). In some plants, the increases are as high as 19°C. Maximum temperatures would be reached in <1 min in the condenser and would be maintained for at least 9 min in a diffuser discharge system and at almost maximum temperature, for possibly up to 21 min, in a discharge canal system. Other factors that could cause damage to euphausiids in a cooling system include pressure changes, abrasion, and toxic substances.

I simulated the thermal conditions encountered in a cooling system to determine the temperature increases that *E. pacifica* could resist for short periods (15 and 30 min). This information can be applied to the design and operation of cooling systems to protect zooplankton.

These studies were conducted at the National Marine Fisheries Service's Mukilteo Field Station, Washington, during 1971-74.

Methods

Euphausiids for these experiments were captured during daylight hours in Port Gardner of northern Puget Sound, Washington, between Mukilteo and Gedney Island. A 10-m net with 333-μm aperture Nytex[1] netting was towed at a depth of about 60 m at a rate of 4.6 km/h. Tows were usually of a 5-min duration. A 946-ml glass bottle was used as a collection receptacle to protect the animals.

As soon as the net was retrieved, the catch (consisting mostly of euphausiids) was divided between two or three 18.9-l Nalgene carboys filled with fresh seawater and covered with black polyethylene sheeting to exclude light. The catch was taken immediately to the laboratory, usually <2 km away, where the euphausiids were separated from other organisms in the catch and placed in 5-l battery jars (23 × 14 × 17 cm) of fresh seawater. They were then placed in a dark, low-temperature incubator set at their previous ambient seawater temperature where they were held before and after testing.

The test apparatus consisted of a series of 5-l battery jars filled with seawater that were maintained at specific temperatures by immersion heaters activated by temperature controllers (Craddock 1976). The jars were in a primary bath of running seawater at ambient temperature and air was continuously bubbled into the jars to eliminate stratification.

Test containers for holding the euphausiids were polyvinyl chloride boxes of 5 cm^3 with two opposing sides having 4-cm diameter cutouts covered with 333-μm aperture Nytex netting to allow free water circulation. Styrofoam glued to the boxes provided flotation (Figure 1).

The temperature-time regime to which the euphausiids were subjected was designed to simulate their passage through a condenser cooling system. Coutant (1970) depicted a hypothetical temperature-time course for organisms entrained in condenser cooling water and discharged by diffuser or by discharge canal. An animal could be subjected to maximum temperature increases for up to about 10 min in a diffuser and up to about 20 min in a discharge canal system. Relative to his study, I chose 15- and 30-min exposure tests to represent the longest exposure that might be encountered. To simulate these conditions, test euphausiids were subjected to a given temperature ranging from 14° to 29°C for 15 or 30 min, starting from temperatures of 11° or 9°C. Euphausiids used as controls were always kept at the prevailing ambient temperature (approximately the same as the subsurface temperature of Puget Sound). Five 15-min tests were conducted during June-July 1971, four 30-min tests were run during June-August 1971, and two 15-min tests were made during March-April 1974.

The euphausiids were held 18 h or longer before testing to eliminate handling mortality and were then counted into test containers in seawater while the secondary baths were being raised to the test temperatures. Either 5 or 10 euphausiids were tested in each container, depending upon the numbers available for that particular test.

When all secondary baths became equilibrated at the test temperatures, the boxes containing the euphausiids along with a small amount of water were placed in the test baths. Water in the test containers was within 0.5°C of the test temperature in an average of 28 s after introduction. At the end of the exposure period, the test boxes containing the euphausiids were removed from seawater at the test temperature and placed in fresh seawa-

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

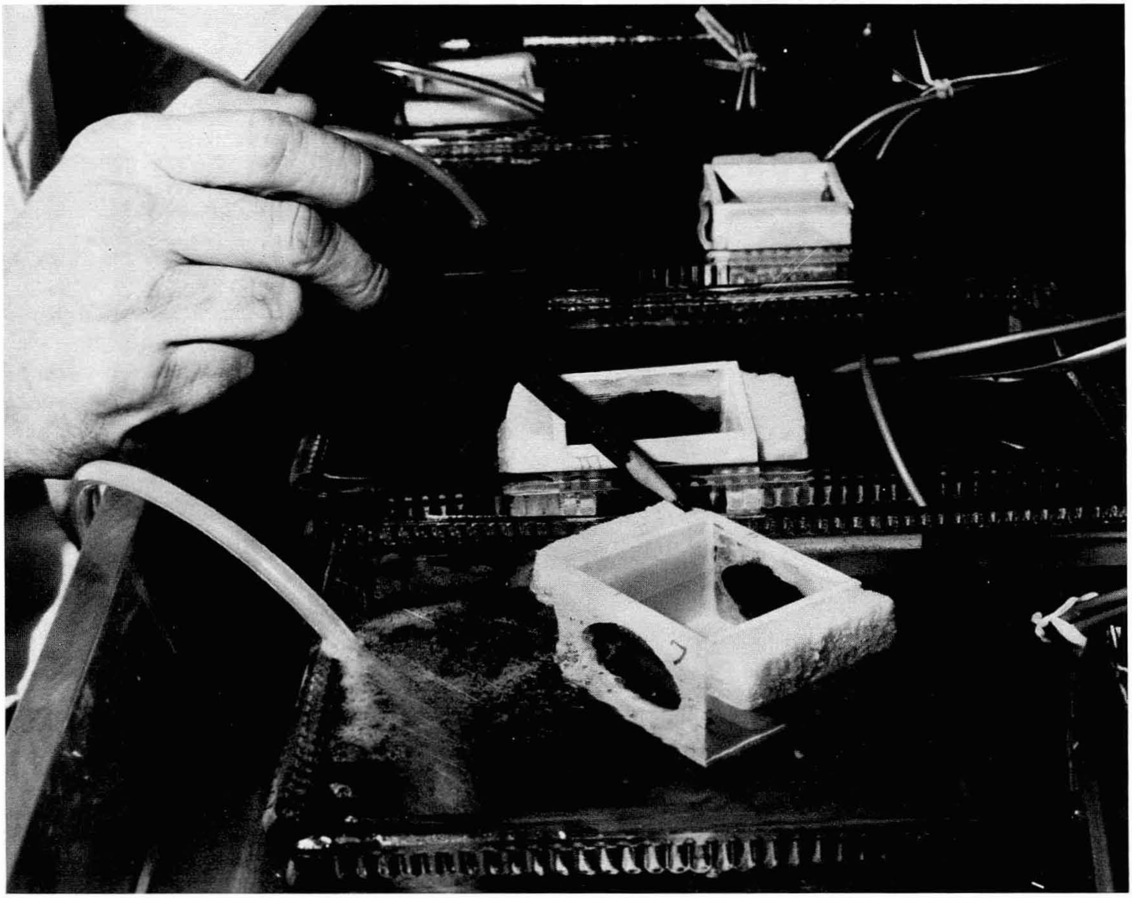

FIGURE 1.—Test chambers and apparatus for testing thermal effects on *Euphausia pacifica*.

ter at the acclimation temperature and maintained in the low temperature incubator. All lots were checked for mortality at 5, 10, and 15 min after introduction to the test temperature when the duration of the exposure was 15 min and also at 20 and 30 min after introduction for the 30-min exposure. All were again checked at 1, 24, and 48 h after testing. The 48 h survival was taken as diagnostic for the TL_{50}'s.

Temperature effects were evaluated on the basis of mortality during tests and 48 h after testing. Forty-eight hours was assumed to be a reasonable holding period to check for delayed mortalities—yet not long enough to cause mortality due to confinement and lack of food. A euphausiid was considered dead if no movement of the thoracic appendages, pleopods, or antennae could be detected using 3 × magnification. I modified the term median tolerance limit (TL_{50}) to indicate the maximum 15- or 30-min exposure temperature survived by at least 50% of the experimental animals 48 h after testing. This should be considered the maximum temperature-time combination resisted.

Lengths of the test animals between the extreme tips of the rostrum and telson were taken at the end of each test. The mean-lengths of the euphausiids tested at the various seasons ranged from 12.11 to 18.37 mm (Table 1). The actual range was from 9 to 27 mm. Those tested in the early part of June were the largest; they exceeded those tested later in June by an average of 6.26

TABLE 1.—Sizes (millimeters) of *Euphausia pacifica* tested.

Dates	Mean	Range	Dates	Mean	Range
1971:			1974:		
June 2-9	18.37	14-26	Mar. 12	14.15	10-20
July 21-30	12.11	9-16	Apr. 12-16	13.85	10-23
Aug. 4-11	13.14	10-19			

mm. Those tested in August, March, and April had an average spread of only 1.01 mm.

Results

Controls in the different tests suffered no mortality during the exposure period except the June-July tests, where the 15-min group lost 7% of controls by the end of 48 h and the 30-min group lost 10% by the end of 48 h. The data were corrected to reflect the loss of the controls in the June-July tests, using the method of Tattersfield and Morris (1924) as reported by Sprague (1969).

Acclimation temperature influenced resistance. The TL$_{50}$ of euphausiids given a 15-min exposure to elevated temperature was 25°C for those acclimated to 11°C; it was 23°C for those acclimated to 9°C. Exposure to 26°C resulted in survivals of 32% and exposure to 27°C resulted in almost immediate death (<15 min). In the 15 min 9°C acclimation test (March-April 1974), the TL$_{50}$ was at 23°C and 47% were still surviving 48 h after exposure at 24°C. However, 15 min after exposure to 25°C, only 13% remained alive and all were dead in <15 min at 26°C. Figure 2 depicts the survival after a 15- and 30-min exposure to elevated temperatures and after a 48-h holding period.

Increasing the duration of exposure to test temperatures from 15 to 30 min when the ambient temperature was 11°C decreased the TL$_{50}$ by 1° to 24°C. Of those tested at 25°C, only 44% survived 48 h after testing. At 26°C, only 2.5% survived the 30-min test period. None survived the test period at 27°C.

The logistic model was fitted to the data from the three different thermal shock tests. The probability of survival was taken to be the form P [survival at temperature x] = $1/(1+e^{ax+b})$ where $e = 2.718$. This is the so-called logistic model and a and b are parameters which are estimated using the data. In the 15-min exposure of June-July 1971, $\hat{a} = 0.6544$ and $\hat{b} = -16.4138$; in the March-April 1974 exposure, $\hat{a} = 0.9568$ and $\hat{b} = -22.2860$; whereas in the 30-min exposure July-August 1971, $\hat{a} = 0.5173$ and $\hat{b} = -12.2572$. The estimates of TL$_{50}$ and an approximate 95% confidence interval for it follow for the three tests: 1) 25.08°C, 24.51°-25.65°C; 2) 23.29°C, 22.76°-23.82°C; and 3) 23.69°C, 22.95°-24.44°C.

There was no obvious difference in the effect of a

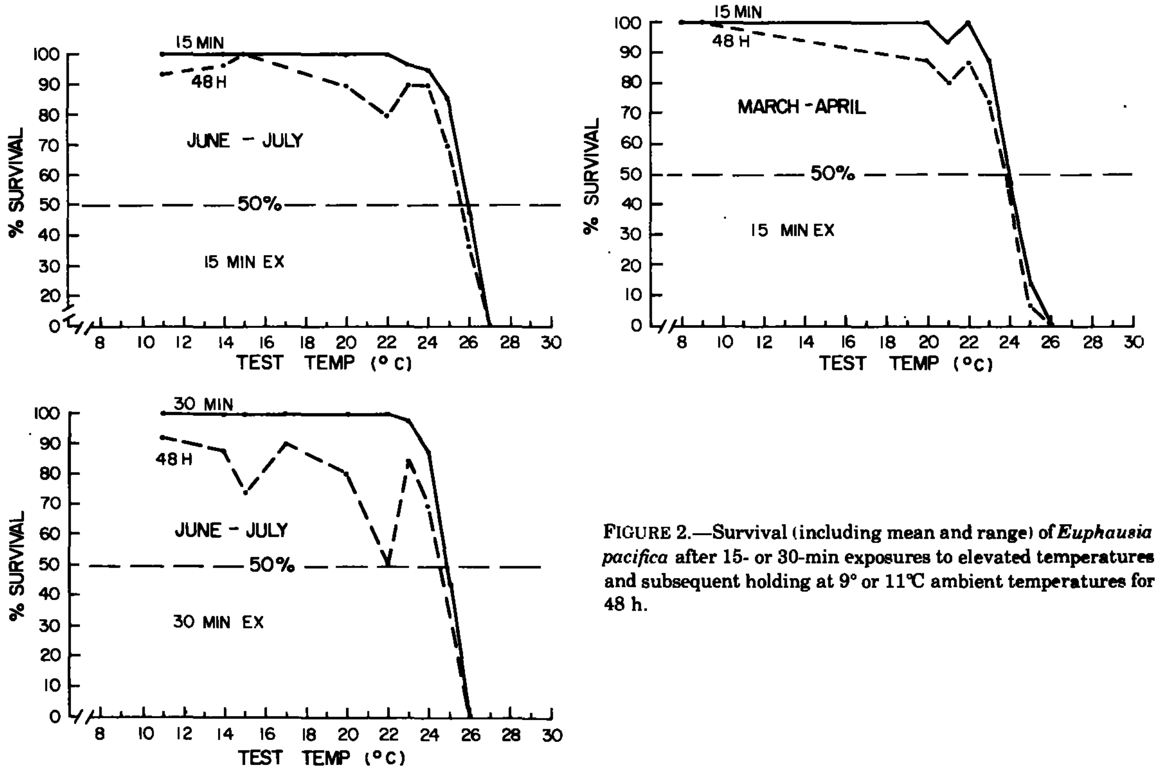

FIGURE 2.—Survival (including mean and range) of *Euphausia pacifica* after 15- or 30-min exposures to elevated temperatures and subsequent holding at 9° or 11°C ambient temperatures for 48 h.

short exposure to increased temperature on the largest or the smallest euphausiids tested. Two out of three groups tested for 15 min in early June (the largest euphausiids) exceeded 50% mortality after exposure to 26°C as did the two groups tested in late July (the smallest euphausiids).

Discussion

The intake of a condenser cooling system may entrain large quantities of euphausiids—depending to some extent on the depth of the intake, the season of the year, and even the time of the day. During the summer, fall, and winter, the young euphausiids make diurnal vertical migrations from the 50- to 100-m strata, rising daily to the surface during the dark hours. After sexual maturity in the early spring they descend even deeper until they inhabit depths over 200 m during their second winter. The following spring they rise to the surface for the second time to breed. The young euphausiids thus spend much of their first year at depths above 50 m, and older adults are again near the surface in the spring (Ponomareva 1963).

Gilfillan (1972) pointed out that *E. pacifica* is widely distributed and is abundant in water having differing temperature characteristics. His studies showed that *E. pacifica* from the Pacific Ocean were more easily stressed by changes in temperature and salinity than those from the west entrance of Strait of Juan de Fuca—which, in turn, were more readily stressed than those from Saanich Inlet. His results indicate that *E. pacifica* from inner Puget Sound would be among the most resistant to thermal stress of these different groups.

Temperatures encountered by euphausiids in Puget Sound normally vary only slightly from the surface to 100 m and deeper. From October through about May there is usually no change in temperature from the surface to 100 m, whereas in the summer the surface to 10 m or less may be a few degrees warmer (Lincoln and Collias[2]).

Seasonal temperature variations in most of Puget Sound are also small, ranging from a low of 7° or 8°C in February to 11°C in late July, August, and September. Even considering their vertical migrations in summer, euphausiids are normally subjected to only slight temperature fluctuations and, therefore, the mortalities observed at simulated condenser cooling temperatures are not surprising.

Once entrained in a condenser cooling system, the euphausiids would encounter an abrupt temperature increase of 12°-16°C (Coutant 1970), which could increase temperatures above the ambient temperature of Puget Sound to the critical range for survival. There are periods from July through September when surface temperatures may reach or exceed 15°C in portions of Puget Sound (Lincoln and Collias see footnote 2). Normally, surface temperatures do not exceed 14°C. Cooney (1971) noted high surface temperatures in June of 16.7°-19°C. These temperatures could result in condenser cooling temperatures of 27°C and above, which this study found to be 100% lethal in a very short time.

Data from this study indicate that even a short passage time through a condenser (15 min) at temperatures of 23°-24°C could kill from 11 to 53% of the euphausiids by thermal causes alone. The added loss due to abrasion, pressure, and toxic substances is unknown.

To minimize damage to the euphausiid populations, condenser cooling system intakes should be located deep enough to take advantage of the coldest cooling water available to minimize temperatures in the system. A very deep intake (just below 100 m) would probably minimize the entrainment of euphausiids. A surface intake would be especially harmful because of the higher surface temperatures and because of the swarming of euphausiids on the surface. Plant lights at night could cause the surface swarming.

Literature Cited

COONEY, R. T.

1971. Zooplankton and micronekton associated with a diffuse sound-scattering layer in Puget Sound, Washington. Ph.D. Thesis, Univ. Washington, Seattle, 208 p.

COUTANT, C. C.

1970. Entrainment in cooling waters: Steps toward predictability. Proc. 50th Annu. Conf. West. Assoc. State Game Fish Comm., p. 90-105.

CRADDOCK, D. R.

1976. Effects of increased water temperature on *Daphnia pulex*. Fish. Bull., U.S. 74:403-408.

GILFILLAN E.

1972. Reactions of *Euphausia pacifica* Hansen (Crustacea) from oceanic, mixed oceanic-coastal and coastal waters of British Columbia to experimental changes in temperature and salinity. J. Exp. Mar. Biol. Ecol. 10:29-40.

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[2] Lincoln, J. H., and E. E. Collias. 1970. Skagit Bay Study Progress Report No. 3. Univ. Wash. Dep. Oceanogr., Seattle, Ref. M70-111, 88 p.

PONOMAREVA, L. A.
1963. Evfauziidy severnoi poloviny Tikhogo okeana, ikh rasprostranenie i ekologiya massovykh vidov (Euphausiids of the North Pacific, their distribution and ecology). Moscow, Izd. Akad. Nauk SSSR, 142 p. (Translated Isr. Program Sci. Transl., 1966, 154 p.; available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, Va., as TT 65-50098.)

SPRAGUE, J. B.
1969. Review paper: Measurement of pollutant toxicity to fish. I. Bioassay methods for acute toxicity. Water Res. 3:793-821.

TATTERSFIELD, F., AND H. M. MORRIS.
1924. An apparatus for testing the toxic values of contact insecticides under controlled conditions. Bull. Entomol. Res. 14:585-590.

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LUNAR SPAWNING OF THE THREADFIN, *POLYDACTYLUS SEXFILIS*, IN HAWAII[1]

Recent evidence indicates that lunar spawning rhythms are more common in fishes than was once thought. Johannes (1978) listed 50 species of teleost fishes with lunar spawning rhythms, most of them tropical and all of them marine or catadromous. In the course of developing methods for culturing the threadfin, *Polydactylus sexfilis* (Cuvier and Valenciennes), we found that this species displayed a lunar spawning rhythm (May 1976). The lunar pattern of spawning had been indicated by a previous field study (Lowell 1971) and is consistent with fishermen's lore (Hosaka 1944), but proof was lacking and details of the rhythm were unknown. In this paper we present detailed information on the lunar spawning of *P. sexfilis* along with observations of spawning behavior, using results from captive fish.

Polydactylus sexfilis is a much sought-after food fish in Hawaii and supports an important sport fishery as well as a small commercial fishery (Rao[2]). Information on the life history of this species (Lowell 1971; Morris and Kanayama[3]) indicates that spawning takes place close to shore. The larvae and juveniles lead a pelagic existence for about 3 mo, juveniles moving to shallow inshore areas at fork lengths (FL) between about 50 and 100 mm. The fish become sexually mature males at 20-25 cm FL and subsequently undergo a sex reversal, passing through a hermaphroditic stage and becoming functional females between 30 and 40 cm FL. Adults inhabit inshore rocky and sandy areas, frequently in zones of turbulence.

Methods

Juvenile *P. sexfilis* were captured by seine on reef flats along windward Oahu in September and October 1970 and reared to sexual maturity in tidal ponds at Coconut Island, in Kaneohe Bay, Oahu. The fish were daily fed chopped squid or smelt, commercial trout chow (40% protein), or trout chow supplemented with chopped squid. In May 1973, 30 mature fish (18 females and 12 males) were transferred to a 18-m^3 nylon net enclosure suspended from Styrofoam[4] floats and anchored off the leeward (southwest) side of Coconut Island. In June and July 1973, a small number of these fish were removed to laboratory tanks and used in experiments on hormone-induced spawning. During this work, ovarian biopsy samples were examined which contained residual eggs and indicated that the fish had been spawning spontaneously. In order to monitor any such spawning, an airlift egg collector was installed (May et al.[5]) in the center of the net in July 1973 and operated continuously (except for a few days when equipment malfunctioned) between 14 July 1973 and 31 December 1975. *Polydactylus sexfilis* produces pelagic eggs, so that the collector obtained a sample of eggs at each spawning. Every morning the entire contents of the collector were harvested and examined under a dissecting microscope, and the number of *P. sexfilis* eggs was estimated by sub-

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[1] Contribution No. 552, Hawaii Institute of Marine Biology.

[2] Rao, T. R. 1977. Enhancement of natural populations of moi (*Polydactylus sexfilis*) in Hawaii through the release of hatchery-reared juveniles - a feasibility study of sea ranching. Univ. Hawaii, Hawaii Inst. Mar. Biol., Tech. Rep. 33, 46 p. Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, HI 96744.

[3] Morris, D. E., and R. Kanayama. 1964-69. Life history study of the moi, *Polydactylus sexfilis*. Job Completion Rep., Projects No. F-5-R-11 to F-5-R-17, Div. Fish Game, State of Hawaii. Division of Fish and Game, Honolulu, Hawaii.

[4] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[5] May, R. C., G. S. Akiyama, and M. T. Santerre. 1976. A simple method for monitoring the spawning activity of fish in net enclosures. International Milkfish Workshop-Conference, May 19-22, 1976, Tigbauan, Iloilo, Philipp. Working Pap. 10, p. 133-138. Southeast Asian Fisheries Development Center, Kalayaan Building, Dela Rosa corner Salcedo Sts., Makati, Metro Manila, Philipp.