

Water Quality Requirements for First-feeding in
Marine Fish Larvae of the Cape of Good Hope,
with Descriptions of Developmental Stages

by

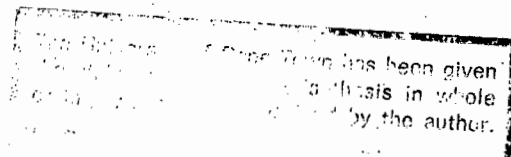
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Part 1.

Water quality requirements for
first-feeding in marine fish larvae:
ammonia, nitrite, nitrate, pH,
oxygen, and carbon dioxide

ABSTRACT

The tolerance of marine fish larvae to NH_3 , NO_2^- , NO_3^- , H^+ , OH^- , O_2 , and CO_2 was investigated using the decrease in first-feeding incidence following a 24-h exposure as the criterion of response. Ten species, all hatched from pelagic eggs collected at sea, were used in the studies: two soleids (Heteromycteris, Synaptura), a cynoglossid (Trulla), a gadid (Gaidropsarus), a congiopodid (Congiopodus), four sparids (Diplodus, Lithognathus, Pachymetopon, and an unidentified species), and a centracanthid (Pterosmaris). Concentrations that inhibited first-feeding are compared to 24-h LC_{50} 's for the same species, and to concentrations that are known to induce lethal and sublethal responses in other teleost species. Judging from their effect on first-feeding, un-ionized ammonia, elevated pH, and reduced oxygen concentration are considered to be potential hazards in the rearing tank. NO_2^- , NO_3^- , H^+ , and free CO_2 are non-toxic at levels likely to be encountered in practical fish culture. There are only minor inter-specific differences in calculated 24-h first-feeding EC_{50} 's (concentration that reduces first-feeding incidence by 50%), which suggests general applicability of the results to a wide variety of first-feeding marine fish larvae. Data are presented on the age at first-feeding and point-of-no-return. The suitability of assorted micro-particles (including the rotifer, Proales, and pine pollen) as experimental foods is discussed.

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1. INTRODUCTION

The marine pisciculturist cannot hope to duplicate, in culture, the conditions to which pelagic marine fish larvae have come to be adapted over a period of, perhaps, millions of generations. In order to obtain economically acceptable rates of survival and growth, however, he must satisfy a substantial number of requirements—physical, chemical, and biological. His task will be facilitated if he can first separate the critical factors from the non-critical, and concentrate his efforts, and capital, on the former. Enlightened decisions as to which factors are critical, and to what degree, are largely made possible by the contributions of pollution biology. Within the sphere of freshwater pisciculture, the reviews by Ellis (1937), Doudoroff & Katz (1950, 1953), Doudoroff & Shumway (1970), and EIFAC (1968, 1970), to mention only a few, provide invaluable introductions to the environmental requirements of fish.

The marine sphere has been, until recently, comparatively neglected. That this is no longer the case is apparent from the tremendous discharge of literature over the past several years (see bibliographies assembled by the Marine Pollution Information Centre, Marine Biol. Assoc. U.K., Plymouth: "Marine pollution research titles"). Paralleling the course of events in the freshwater domain, a decided improvement in our understanding of the requirements of marine fish in culture is likely to result from this expanding interest in marine pollution biology.

The establishment of tolerance limits of fish to pollutants (or to sub-optimal conditions) is most often experimentally achieved by relating the concentration of pollutant (or "magnitude" of sub-optimal conditions) to some measureable, and presumably deleterious, response. Primarily for reasons of simplicity, the response of choice has

traditionally been death, within a stated exposure period. When one is concerned with the growth rate of fish in a tank, or the long-term health of a natural population, more subtle, sublethal responses are certainly more meaningful. A list of the sublethal responses that have actually been employed, let alone suggested, for fish toxicity testing would run to several pages. Reviews on the subject (eg, Warner, 1967; Sprague, 1971; Mitrović, 1972; Waldichuk, 1973; Rosenthal & Alderdice, 1976) are now available.

In the present study, the inhibition of first-feeding was chosen as the response; ammonia, nitrite, nitrate, low and high pH, low dissolved oxygen, and carbon dioxide were tested as potential inhibiting factors. That the first-feeding stage is among the more sensitive to sub-optimal conditions is suggested by even the large number of published failures of investigators to rear marine fish beyond that stage in the laboratory. Of course, failure in many of these cases can as easily be attributed to the unavailability of a satisfactory food. Nevertheless, in their review of sublethal effects of environmental stressors on marine fish eggs and larvae, Rosenthal & Alderdice (1976:2061) concluded:

"Available data suggest that several stages in the life cycle of marine fishes are more susceptible to environmental and pollutional stress. These are a) gonadal tissue, b) the highly plastic early embryo, and c) the stage of larval transition between reliance on endogenous and exogenous sources of food."

A decline in food consumption, or "loss of appetite", among fish during periods of stress has been recorded by many authors. Those that deserve mention in the present context are Wilson (1972), who studied the deleterious effect of an oil dispersant (BP1002) and Alderson (1972), who studied the effect of free chlorine and its derivatives, on feeding in plaice (Pleuronectes platessa) larvae; Struh-saker et al. (1974), who studied the effect of benzene on feeding in Pacific herring (Clupea harengus pallasii) larvae; and Blaxter (1977), who studied the effect of copper on

feeding in Atlantic herring (Clupea harengus harengus) and plaice larvae. It should be noted that Eldridge et al. (1977) reported increased food consumption and growth among Pacific herring larvae exposed to low concentrations of benzene. The use of the first-feeding response in evaluating the potential of a parcel of water to support survival was pioneered by Lasker (1975).

The kinds of environmental stressors that, in the present state of the art, are of particular interest to the intensive mariculture manager or engineer are those that originate with the cultured organisms, themselves, or with their food. It is these factors that may determine water re-use rates, stocking density, and other considerations relating to water quality management. Ammonia, nitrite, nitrate, pH, oxygen, and carbon dioxide are examined in this study with the object of identifying and quantifying those that are likely to cause concern in a marine fish hatchery/nursery operation. The concentrations of these variables that deleteriously affect first-feeding success in marine fish larvae are compared with lethal concentrations for the same larvae, and with published values for other teleost species, both freshwater and marine.

1.1 NH_3

Ammonia can be expected to occur wherever fish are reared. Although significant amounts of other protein catabolites may also be released, ammonia is the major form of excreted nitrogen in teleost fish, in the invertebrates that are commonly maintained in rearing tanks as food, and in the bacteria living heterotrophically on nitrogenous substrates. The literature on the toxicity of ammonia to fish (almost exclusively freshwater species) has been reviewed several times. The most thorough seem to be the reviews by Doudoroff & Katz (1950) and EIFAC (1970). Although some published information is available on the effect of ammonia on the eggs and larvae of a few freshwater fish species (particularly salmonids), none

was found on the tolerance of the eggs and larvae of marine fish to ammonia. The literature on the physiological and pathological consequences of ammonia toxicity to fish may be approached via articles by Smart (1976, 1978), Lloyd & Swift (1976), and Sousa & Meade (1977).

Aqueous ammonia takes two principle forms: the un-ionized NH_3 (and NH_4OH) and the ionized NH_4^+ . The un-ionized form, because of its membrane permeability, is often assumed to be solely responsible for deleterious effects. There is some evidence, however, that toxicity may also depend (though to a far lesser extent, particularly in the case of fish) on the concentration of the ionized fraction (Tabata, 1962; Armstrong et al., 1978).

Reliable dissociation constants for ammonium in sea water were unavailable prior to Whitfield's (1974) theoretical study. Several authors subsequently published tables (Wickins, 1976; Bower & Bidwell, 1978) or graphs (Hampson, 1977) relating pH, temperature, and salinity to the dissociation on ammonium, based more or less on Whitfield's recommendations. Following publication by Khoo et al. (1977) of experimentally derived dissociation constants, Whitfield (1978) confirmed the accuracy of his earlier predicted values.

1.2 NO_2^-

Because it is an intermediate in the bacterial nitrification of ammonia, nitrite is of considerable interest to biologists involved with recirculating fish-culture systems. The most recent review of the literature on the effects of nitrite to fish appears to be that of Russo & Thurston (1977). A look at the assembled data reveals a surprising variability in tolerance, from species to species and from publication to publication. Much of this variability can now be explained by differences in the ionic constitution of the dilution waters used in tolerance tests. Weber (1966) noted a decrease in nitrite toxicity to guppies (Poecilia reticulata) when Ca^{2+} was added to the dilution water. Russo & Thurston (1977) and Perrone & Meade (1977) found a similar decrease when Cl^- was present. Wedemeyer & Yasutake (1978) confirmed these findings. Crawford & Allen

(1977) reported a dramatic decrease in the toxicity of nitrite to chinook salmon (Oncorhynchus tshawytscha) in sea water, as opposed to fresh water.

Studies on the tolerance of early stages of fish to nitrite seem to be limited to young (1-3 g) trout: Russo et al., 1974: Salmo gairdneri and Thurston et al., 1978: Salmo clarki. Aside from Crawford and Allen's (1977) experiments with chinook salmon, and a reference by Wickins (1976) to a personal communication from R. Alderson (Fish. Lab., Port Erin, Isle of Man, U.K.) noting a greater resistance of turbot (Scophthalmus maximus) to nitrite than freshwater fish, no published information appears to be available on the effect of nitrite on marine fish—at any stage.

1.3 NO_3^-

The origins and consequences of nitrate in recirculating marine culture systems were treated by Kinne (1976), and the subject can be introduced here by quoting directly from his review (p. 97): 1) "Nitrite and nitrate accumulations in culture systems are less dangerous to marine animals than NH_3 accumulation. According to Kelley (1965), nitrate is less toxic than ammonia by about three orders of magnitude." 2) "However, very high nitrate levels may interfere with respiratory processes, especially in invertebrates (e.g. Oliver, 1957; Hirayama, 1966; Kuwatani et al., 1969)." 3) "At nitrate levels of 75 to 100 mg l^{-1} , hermit crabs showed discomfort; 250 to 350 mg l^{-1} are lethal to many fishes (De Graaf, 1964)." 4) "In closed sea-water systems... nitrate levels should not be in excess of 20,0 mg l^{-1} (King & Spotte, 1974)."

Several authors have reported on the toxicity of nitrate to freshwater fish, e.g. Jones (1939: Gasterosteus), Trama (1954: Lepomis), Wallen et al. (1957: Gambusia), Knepp & Arkin (1973: Micropterus and Ictalurus), Westin (1974: Salmo and Oncorhynchus), and Colt & Tchobanoglous (1976: Ictalurus). Studies on the tolerance of early stages of

fish to nitrate seem to be limited to those of Rubin & Elmaraghy (1977) on young (6-11 mm) guppies. Brandenburg (1966) and Braun (1972, cited by Bohl, 1977) associated a loss of appetite with high nitrate concentrations. The sensitivity of early stages of marine fish to nitrate has apparently not been investigated.

1.4 H^+

The decline in the pH of recirculated water is chiefly attributable to the bacterial oxidation of excretory ammonia. From the stoichiometries of the reactions involved, Wickins (1976) calculated that the oxidation of 1 mg of nitrogen as NH_4^+ to nitrogen as NO_3^- requires 4,27 mg O_2 and 0,09 mg inorganic carbon, and produces 0,14 mg H^+ . The decrease in pH is compounded by a simultaneous loss of carbonate alkalinity and consequent decline in the buffering capacity of the recirculated water.

The sensitivity of freshwater fish to low pH has been extensively studied (reviews are available from Doudoroff & Katz (1950), EIFAC (1968), and others). The conclusion drawn in the two reviews mentioned is that, in the absence of other adverse conditions, the juveniles and adults of a wide variety of freshwater fish can tolerate indefinitely a pH as low as 5,0. A few species can tolerate considerably lower pH's (Dunson et al, 1977: Cheirodon). Beamish (1972: Catastomus) noted an inhibition of feeding at low pH—while Ryan & Harvey (1977: Ambloplites) detected an increase in growth rate among fish in an acid lake. Requirements for survival through egg and larval stages were still poorly known at the time of the EIFAC review. This gap has since been partially filled for freshwater fish (Milbrink & Johansson, 1975; Johansson & Milbrink, 1976; Trojnar, 1977a, 1977b; and other publications cited by these authors.

The pH of oceanic surface waters in equilibrium with atmospheric CO_2 rarely falls below 8,1; the extreme of pH 7,5 is generally restricted to oxygen minimum zones, usually at depth (Sverdrup et al., 1942). Without evidence to the contrary, one could easily accept the notion (Jones, 1964:107) that marine fish are markedly less tolerant of low pH than freshwater fish. Although the response of certain

marine fish (including early stages) to low pH has been studied (e.g. Bull, 1940; Bishai, 1960), it is rarely possible, from the published reports, to establish whether the observed effects were due to hydrogen ion concentration or concentration of free carbon dioxide.

1.5 OH⁻

Several investigators have published support for the increasingly widespread practice of rearing the early stages of marine fish in the presence of one or more species of planktonic micro-algae (Anon., 1970; Houde & Palko, 1970; Alderson & Howell, 1973; Barnabé, 1976a). The observed enhancement of survival and growth of the larvae has been attributed to various mechanisms (Struhsaker et al., 1973), among them: that the phytoplankton provides food for the herbivorous zooplankters on which the fish are fed; that it extracts nitrogenous metabolites, e.g. ammonia, that could otherwise reach harmful levels; that it releases anti-bacterial, or even growth-enhancing substances into the rearing water. The effect of phytoplankton growth of interest here is the increase in pH that is brought about indirectly by the extraction of free CO₂ from the water.

Alderson & Howell (1973) monitored pH in aerated rearing tanks (stocked with juvenile sole), with and without phytoplankton (Dunaliella). Between the 8th and 13th day of their experiment, the phytoplankton concentration in the two tanks with algae rose from 300 cells μl^{-1} to 800 cells μl^{-1} . During the same period, pH rose from about 8.4 to about 8.8. The two control tanks without algae remained below about pH 8.2 throughout the experiment. The authors reported a virtual elimination of ammonia from the algae-inoculated tanks, and a slight, but significant, increase in growth among the fish in those tanks.

The tolerance of freshwater fish to high pH has been widely investigated, and publications on the subject have been reviewed by Doudoroff & Katz (1950), Jones (1964), and

EIFAC (1968), among others. The literature includes a few reports on the tolerance of eggs and larvae (e.g. Krishna, 1953: Salmo?; Bishai, 1960: Salmo; Volodin, 1960: Lota (cited by EIFAC, 1968); Bonn, 1970: Morone (cited by Humphries & Cumming, 1973)). The tolerance of marine fish to hydroxyl ion remains very poorly known. The only studies encountered on the tolerance of early stages of marine fish to elevated pH were those of Powers & Logan (1925), Schach (1939), Kelley (1946), and Bishai (1960). Powers & Logan used NaOH to increase the pH of sea water in which they placed pregnant shiner surfperch (Cymatogaster aggregatus). Although the newborn larvae appeared to tolerate the high pH, they died immediately on being transferred to ordinary sea water. The authors failed to report the pH of the water, however, and it is doubtful that the same results would be obtained by repeating the experiment. Schach reported limits of pH tolerance of Atlantic herring (Clupea harengus harengus) larvae but did not explain the methods employed in obtaining them. Bishai used NaHCO₃ to increase the pH of sea water to which he exposed yolk-sac larvae of Atlantic herring. He did not report the number of larvae tested, made no mention of controls, and did not record the amount of bicarbonate added. There is no reason to question the reliability of the data provided by Kelley on the hatching success of Pacific herring (C. h. pallasii) eggs at elevated pH's.

1.6 O₂

Reviews of the literature on the dissolved oxygen (DO) requirements of fish have been compiled by Doudoroff & Shumway (1970) and Davis (1975), among others. Marine fish have received only a fraction of the attention devoted to freshwater species. Available data on the response of marine fish larvae to low DO comes almost entirely from the following five publications: Bishai (1959: Clupea, Cyclopterus), Deubler & Posner (1963: Paralichthys), Saksena & Joseph (1972: Chasmodes, Gobiosoma, Gobiesox), De Silva & Tytler (1973: Clupea, Pleuronectes), and Sylvester et al. (1975: Mugil). The tolerance of the eggs of a few marine, non-anadromous teleosts has also been studied: Alderdice & Forrester (1971:

Gadus), Braum (1973: Clupea), Sylvester et al. (1975: Mugil) and King (1977: Sardinops).

From the literature on the DO requirements of various stages in the life cycles of teleost fish, it can be concluded (though, not entirely without reservation) that the period beginning just prior to hatching and ending with the development of branchial respiration is the most sensitive to low DO. Such a period is present in most marine and freshwater teleosts with small eggs. The reservation arises mainly from the fact that little attention has yet been paid to effects on spawning and other behavior-related processes critical to population survival. (Two exceptions are Brungs (1971: Pimephales) and Siefert & Herman (1977: Pomoxis)). There are several indirect reasons to suspect that marine fish larvae relying on cutaneous respiration would be particularly sensitive to low DO, and that this sensitivity would be aggravated in culture: 1) It is during the early feeding stages that maximal density of food is required (Rosenthal & Hempel, 1970; Blaxter & Stains, 1971; Hunter, 1972), which, directly and indirectly, contributes to the biological oxygen demand of the rearing water. 2) The turbulence and shearing forces arising from direct aeration (Lumare & Villani, 1973) or spraying (Pommeranz, 1974) of tank water can be deleterious during the pre-feeding and early feeding stages. 3) Although sea water can be more efficiently aerated than fresh water (Kils, 1977), the DO content of air-saturated sea water is about 20% less than that of air-saturated fresh water at the same temperature. 4) The toxicity of several substances, including ammonia, may be increased by decreases in DO (e.g. Downing & Merkins, 1955: ammonia; Cairns, 1957: zinc, cyanide, and naphthenic acid; Lloyd, 1961: ammonia, zinc, lead, copper, and monohydric phenols). 5) Certain of the compensatory mechanisms available to fish with branchial respiration and haemoglobin, i.e. increasing opercular frequency and amplitude (Hughes, 1973), and haemoconcentration (Swift & Lloyd, 1974), are obviously not possible during the phase of cutaneous respiration. Increased

swimming activity or pectoral fanning might achieve the required ventilation, but at the cost of a higher metabolic rate: In the California sardine (Sardinops caerulea), oxygen consumption during periods of activity was measured at about $3\frac{1}{2}$ times that at rest (Lasker & Theilacker, 1962), and as much as 10 times in larvae of the herring (Clupea harengus) (Holliday et al., 1964).

The connection between low DO and loss of appetite reported by Stewart et al. (1967: Micropterus), Andrews et al. (1973: Ictalurus), and Randolph & Clemens (1976: Ictalurus), among others, coupled with the above considerations, supports the proposition (Iwai & Hughes, 1977) that the maintenance of adequate DO might be a very critical requirement for first-feeding success in marine fish larvae. The experiments conducted in the present study were designed to measure the ability of several marine teleosts to first-feed following exposure to various sub-optimal levels of DO.

1.7 CO₂

Carbon dioxide in a rearing tank for larval fish is generated by the respiratory activities of bacteria, living fish food, and the fish themselves. The literature on the effects of CO₂ on fish physiology and survival is not extensive; it has been reviewed by Doudoroff & Katz (1950), Fry (1957), and Jones (1964). In general, the reviewers conclude that fish are very tolerant of elevated concentrations of free CO₂, particularly when they are allowed sufficient time to acclimate. Although the ability of fish to extract oxygen from surrounding water diminishes at abnormally high concentrations (the "Root effect"), the "ordinary environmental levels of carbon dioxide have little influence on the rate of oxygen consumption" in all but the "most sensitive species" (Fry, 1957:46). Fry stressed that considerable work needed to be done on the subject.

Aside from Kelley's (1946) experiment with herring (Clupea harengus pallasii) eggs, there appears to have been no attempt to determine the tolerance of marine fish eggs or larvae to elevated free CO₂ concentrations. The wide variation in CO₂ concentration during her experiment renders the results very difficult to interpret.

2. SUPPLY AND HANDLING OF LARVAE FOR EXPERIMENTAL PURPOSES

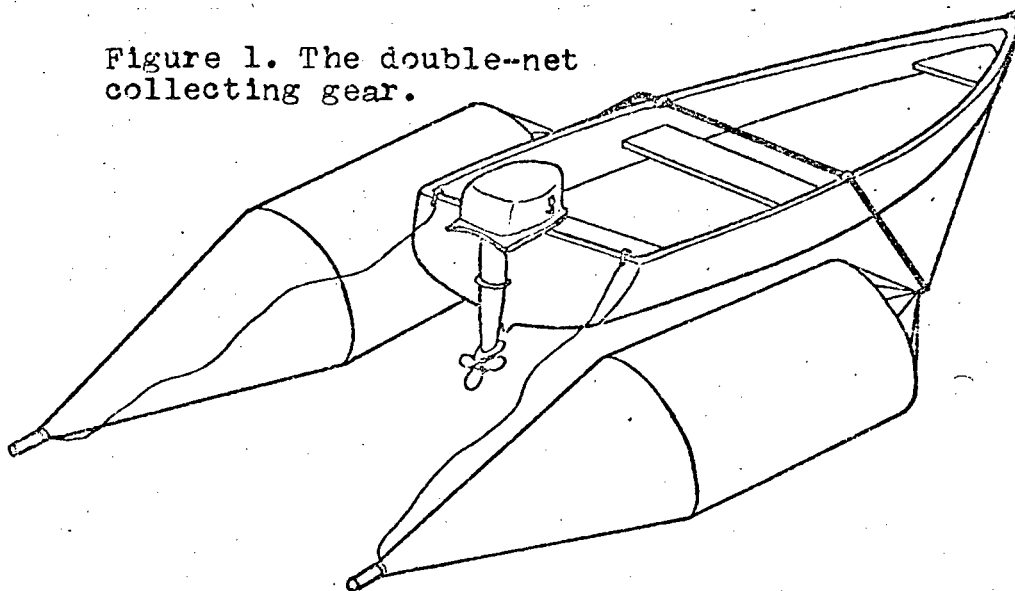
2.1 Collection and handling of eggs

The fish larvae used in both the preliminary studies and tolerance studies came entirely from sea-spawned, pelagic eggs collected by plankton net. The 58 collection outings were distributed almost equally between the Atlantic (off Three Anchor Bay, Granger Bay, and Oudekraal, and in Hout Bay) and the False Bay (off Fish Hoek, Glencairn, and Simonstown) sides of the Cape Peninsula. Tows were made within about 3 km of shore with a 3-m fibre-glass boat, powered by a 4-hp outboard motor. Two plankton nets were fixed to a bent steel beam clamped across the boat in the fashion shown in fig. 1. The nets have mouths of $0,5 \text{ m}^2$ (30 cm diam.), are about 3 m long, and are fitted with a 1,5-l perspex codend that unscrews from a threaded polyethylene ring sewn to the fabric. The ratio of filtering area to mouth area is 7,0:1. The mesh is an inexpensive synthetic cloth sold as curtain material, with openings 1,0 by 0,3 mm. Course mesh (5 mm openings) stretched across the mouth kept the larger ctenophores, medusae, salps, and floating debris out of the nets. The position of the nets relative to the motor meant that care had to be taken to avoid fouling the propeller. This disadvantage was outweighed, however, by the fact that the codends could be alternately drawn into the boat by a cord attached to the polythethylene ring, and emptied every few minutes, without fully cutting speed and without disconnecting the nets. Towing speed varied from 0,5 to 1,0 m sec^{-1} , and an estimated 500-2000 m^3 of water was sieved during a typical sortie. The eggs taken in these collections have been identified (where possible), counted, and tabulated, independently for the two sides of the Cape Peninsula (Part 2 of this thesis).

On return to the laboratory, about 45 minutes later, the eggs were picked out by pipette with the aid of a dissecting microscope, identified to species (when possible), and distributed among a number of incubation baskets floating in the closed-circulation system described below. Sorting

and identification of the eggs was carried out in a constant temperature room set at the eventual incubation temperature of the eggs. Although some samples underwent gradual temperature changes of up to 6°C between collection and deposition in the incubation baskets, none of the eggs is likely to have experienced sudden temperature changes of over 2°C during the various seiving, sorting, and measuring operations.

Figure 1. The double-net collecting gear.



2.2 The seawater system, incubation of eggs, and holding of pre-feeding larvae

The closed-circulation system used for holding eggs and pre-feeding larvae is shown schematically in fig. 2. The water table is 2 m long, 55 cm wide, and has a water depth of 25 cm. It can accomodate about 30 incubation baskets and 20 larva baskets. It is housed in a constant temperature room which maintains the water at $15,0 \pm 0,2^{\circ}\text{C}$. A platform of window glass submerged about 3 cm into the water table at one end serves as a constant temperature bath for experimental containers. Circulation is powered by a single air-lift pump, through which the flow rate varies from $1,5\text{--}2,5 \text{ l min}^{-1}$. Air diffusers immersed in the water table provide additional aeration and circulation of water through the floating baskets.

Filtered ($25 \mu\text{m}$), natural sea water, collected from Three Anchor Bay, Cape Town, was used in the system. The following determinations were carried out on system water at stated

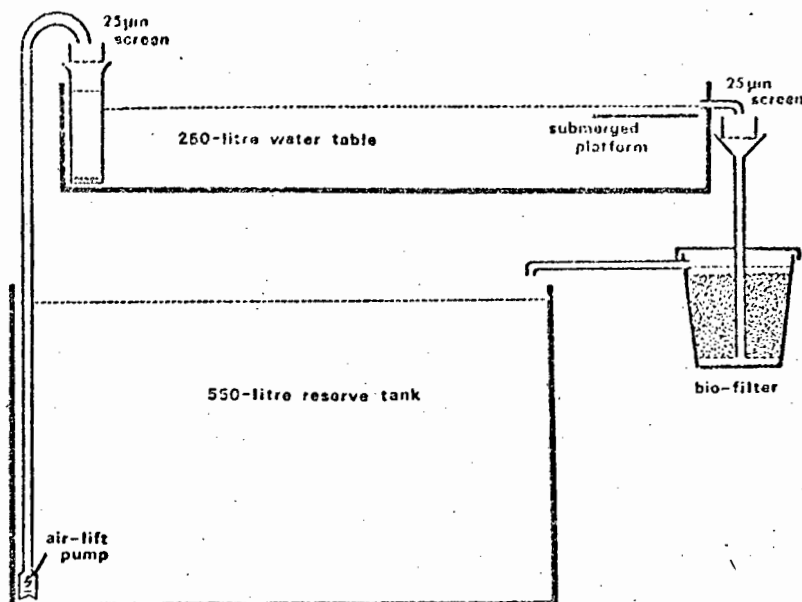


Figure 2. The closed-circulation sea-water system used to hold eggs and pre-feeding larvae.

intervals: temperature (daily); ammonia, nitrate, reactive phosphate, reactive silicate, salinity, pH (monthly); free CO_2 , alkalinity, dissolved O_2 (irregularly). Nitrite was analyzed (monthly) and bacterial concentrations determined by plate count (weekly) during an initial 6-month period. Direct bacterial counts were made on two occasions: the first was after about six months operation, the second after about two years. Distilled water was added to compensate for evaporative loss. NaOH and NaHCO_3 were added to adjust pH and alkalinity, respectively. A summary of the analytical results obtained during two years of use is presented in table 1. Simple, closed-circulation seawater systems of this type, as well as more complex systems, have been described by Kinne (1976:42).

The incubation baskets (fig. 3a) have an effective volume of about 75 ml. The two primary functional considerations in their design were that eggs and newly-hatched larvae be clearly visible, and that the water to which they are exposed be a close approximation to system water, particularly as regards dissolved oxygen concentration. The basket is a nylon mesh (200 μm) truncated cone fixed to

Table 1. Some physical, chemical, and biological characteristics of sea water in the closed circulation system. Where applicable, the range of measured values is given.

<u>physical and chemical factors</u>			
total volume	800-900 l	total ammonia-N ¹	15-66 µg l ⁻¹
flow rate	1,5-2,5 l min ⁻¹	nitrite-N ²	1,3-2,0 µg l ⁻¹
temperature	14,8-15,2 °C	nitrate-N ¹	0,14-1,50 mg l ⁻¹
salinity	34,4-35,7 ‰ S	reactive phosphate-P ¹	50-130 µg l ⁻¹
pH	7,79-7,85	reactive silicate-Si ¹	22-500 µg l ⁻¹
total alkalinity	2,15-2,45 meq l ⁻¹	illumination at water surface	300 lux
free CO ₂ -C	0,37-0,47 mg l ⁻¹		
dissolved O ₂	7,9-8,1 mg l ⁻¹		
<u>biota in the system</u>			
bacteria (suspended):	plate count ³ (ZE2216E medium): 3,4 X 10 ³ - 4,8 X 10 ⁵ cells ml ⁻¹ direct count ⁴ (fluorescence): 6,4 X 10 ⁵ - 9,5 X 10 ⁵ cells ml ⁻¹		
Oscillatoriaceae:	<u>Spirulina ?subsalsa</u> Oerst. ⁵ <u>Phormidium ?purpurascens</u> (Kütz.) ⁵		
Rotifera:	<u>Trichocerca</u> sp.		
Copepoda:	<u>Tisbe</u> sp. ⁶		
Ciliata:	unidentified hypotrichida		

footnotes: 1. analysis by Sybrand Mostert and John Henry, Sea Fisheries Branch, Cape Town
 2. analysis by Kate Trotter, Dept. of Oceanography, Univ. of Cape Town
 3. counts by Hubert Mazure, Dept. of Zoology, Univ. of Cape Town
 4. counts by Anne Linley, Kelp Bed Project, Univ. of Cape Town
 5. identification by Richard Simons, Sea Fisheries Branch, Cape Town
 6. identification by Wilfried Scheibel, Zool. Inst., Univ. Kiel, West Germany

a perspex collar, surrounded by a styrofoam float ring. Eggs floating at the surface come in contact with the perspex collar rather than the mesh, and are thereby not left stranded if the basket is jarred. The mesh and perspex have been stained black, and the water table is lined with black polyethylene. When the room lights are extinguished eggs and hatchlings are readily visible in the beam of a hand-held 6-V microscope lamp.

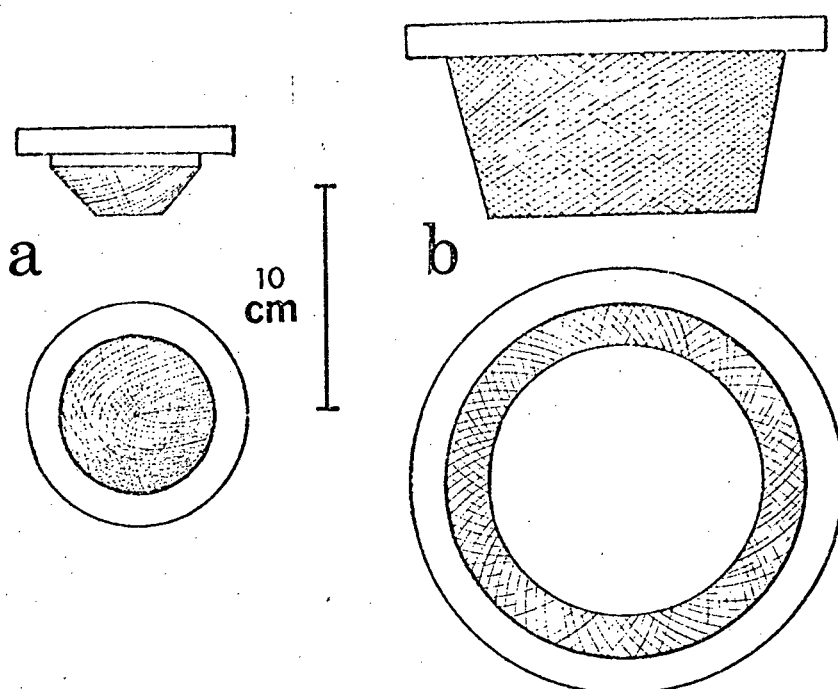


Figure 3. (a) Incubation basket. (b) Larva basket.

The incubation baskets were employed in the following way: Up to about 100 eggs were placed in each basket, and their progress was monitored at approximately 12-h intervals. Larvae having hatched during the previous 12 h were carefully removed by pipette and transferred to larva baskets (fig. 3b). Care was taken to ensure that all hatchlings were removed from incubation baskets, and that no eggs were accidentally transferred to larva baskets along with hatchlings. The time of hatch was recorded as the midpoint of two successive checks.

2.3 Experimental feeding containers

Tolerance testing was conducted in 350-ml, transparent containers (fig. 4a). The cylindrical portions are clear perspex, the front and back walls are glass. The bung (fig. 4b) is made from a 3-cm section of 2,5-cm o.d. perspex tubing; one end is slightly flared and covered by nylon screen

of 200 μm pore size. When the bung is pressed just far enough into the neck of the container to make contact between the mesh and the water surface, the containers can be turned in any direction without leaking. During tests, they were always turned on their sides, with the glass faces in a horizontal position. There were two advantages to this procedure: 1) It eliminated the likelihood of larvae concentrating in the neck of the container (which tended to occur in an upright position), and 2) it seemed to improve feeding ...perhaps by reducing glare or irregular scattering of light within the container. A wad of synthetic wool (of the type used in home-aquarium filters) could be pressed into the bung to limit loss or uptake of gases across the water surface in certain tolerance tests.

Larvae could be examined undisturbed with a horizontally positioned binocular dissecting microscope through the flat glass wall. To simplify manoeuvring the microscope, a system employing an overhead beam and counter-weights was devised.

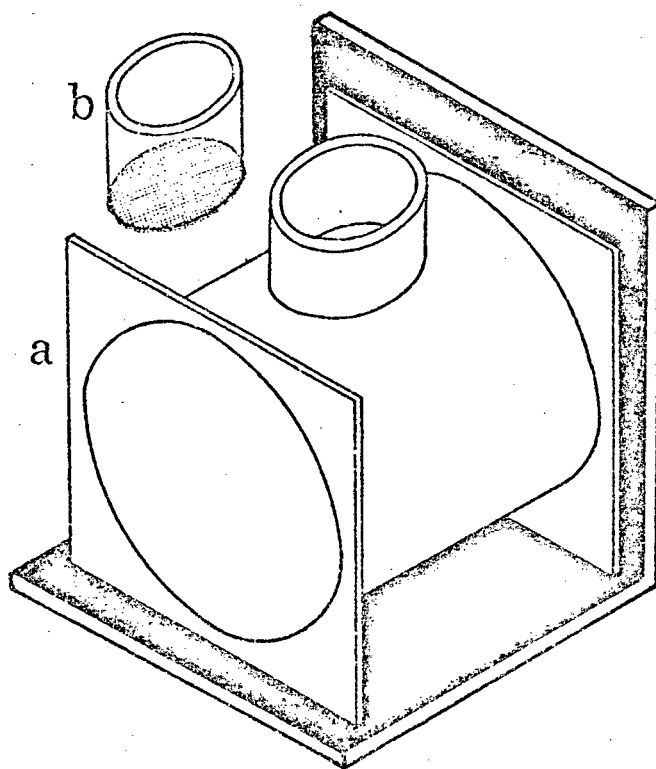


Figure 4. (a) 350-ml feeding container on black stand. (b) Screened bung.

3. PRELIMINARY STUDIES

3.1 Age-at-first-feeding curves

3.1.1 Methods

In order to study the effects of various environmental factors on first-feeding success, it was first necessary to determine, with reasonable accuracy, when first-feeding could be expected to occur. This involved constructing a curve for each species, relating the percent of larvae feeding to the age of the larvae tested. Experimental procedure was as follows: About 300 ml of system water was poured into a 350-ml feeding container. Previously unfed larvae of known (within 6 h) age were pipetted from larva baskets into the container. A concentrated suspension of prey organisms in system water was added to give a final density of roughly 10 (5-20) particles per ml. At first, this density was achieved by direct count of a subsample; later it was determined by eye, once the effect of food density on feeding success had been established. The container was then gently topped up with system water, the screened bung was fitted, and the container laid face-down on a black feeding stand under 3000 lux fluorescent lighting. The larvae were exposed to food for 4 h and then examined with the suspended microscope. One by one, they were rated according to the following system, and removed from the container by pipette:

- a. gut full
- b. gut half-full (larva had apparently been feeding actively, but gut not packed as above)
- c. gut nearly empty (larva had obviously not been feeding actively, but gut not completely empty)
- d. gut empty

In order to obtain quantal response data for the age-at-first-feeding curves, categories a and b were grouped together and considered "fed"; c and d were considered "unfed".

For analysis, test ages were grouped among a number of age-classes of 8 h duration, and the percent of larvae in each group rated "fed" was plotted against the midpoint of each age-class on probability-linear graph paper. Three straight lines were firstly fitted by eye to the resulting distribution of points: an ascending line, corresponding to an initial increase in first-feeding success with age; a horizontal line, corresponding to the phase-of-optimal-first-feeding; and a descending line, corresponding to the decrease in first-feeding success associated with the point-of-no-return phenomenon (PNR). Some refinement in the placement of the lines was achieved as follows: 1) The horizontal line was derived by dividing the number of feeding larvae

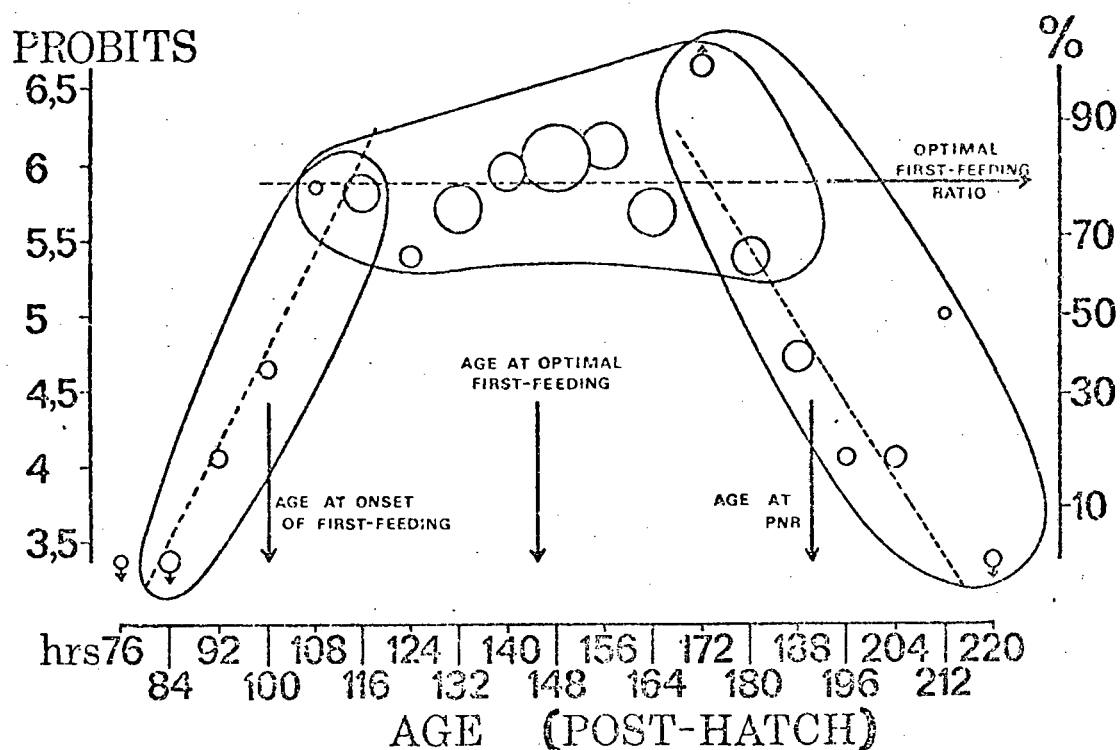


Figure 5. Age-at-first-feeding curve for the Cape rockling, *Gaidropsarus capensis*, feeding on the rotifer, *Brachionus plicatilis*. Circles represent raw data; their areas are proportional to the number of larvae tested in the respective age class. Solid lines surround those circles that were considered (by eye) to contribute to the corresponding dashed lines. A total of 828 larvae are represented in this graph.

in the groups that contributed to that line by the total number of larvae tested in the same groups. The line gives an estimate of the optimal-first-feeding-ratio for the species in question, under the conditions specified.

2) The data contributing to the ascending and descending lines were analyzed by a probit technique (Finney, 1971), treating the midpoint of each age group as the "dose metameter" (x in Finney's notation). The natural response rate (C in Finney's notation) is then equivalent to one minus the optimal-first-feeding-ratio, ie, the proportion of larvae failing to feed during the phase-of-optimal-first-feeding.

Three values were extracted from these curves: the age-at-onset-of-first-feeding, the age-at-PNR, and the age-at-optimal-first-feeding. The age-at-onset-of-first-feeding is defined here as the time interval between hatching and the point when 50% of those larvae that would be expected to feed during the phase-of-optimal-first-feeding (under stated conditions) actually feed. The age-at-PNR is similarly defined: the time interval between hatching and the point when 50% of those larvae that would have been expected to feed during the phase-of-optimal-first-feeding are no longer capable of first-feeding. The age-at-optimal-first-feeding is defined as the arithmetic mean of the age-at-onset-of-first-feeding and the age-at-PNR. The application of this terminology to first-feeding in the Cape rockling is depicted in fig. 5. Fig. 7 shows the same results, expressed on the original coordinates.

To determine the effect of various factors on first-feeding success, tests were timed so that larvae were exposed to food at an age as close as possible to the calculated age-at-optimal-first-feeding for that species at 15°C.

3.1.2 Results and discussion

Curves for eight of the species used in tolerance tests are presented in figs. 6-7. Additional information relating to the age at first-feeding of these species, plus two others (for which curves were not calculated due to incompleteness of data), is presented in table 2. The error associated with calculated ages is estimated to be ± 10 h, but may be as high as ± 15 h.

With the exception of Congiopodus spinifer, all the species mentioned in table 4 hatch in a relatively undeveloped state, with the eyes only becoming pigmented at about the 60th hour (50-70) (Gaidropsarus) to about the 100th hour (85-115) (Sparidae and Centranchidae) post-hatch at 15°C. C. spinifer, as is typical of species with larger eggs, has a longer incubation time and the hatchling is relatively well-developed: the eyes in this species are sometimes already pigmented at hatching. The duration of the first-feeding phase (table 4, taken as the interval between the age-at-onset-of-first-feeding and the age-at-point-of-no-return) is clearly greater in C. spinifer than in the other species. Within the five perciforms tested, there is a weak (non-significant) correlation between egg volume and duration of the first-feeding phase. The soleid, Synaptura, seems to have a relatively short first-feeding phase, considering the size of its egg; the gadid, Gaidropsarus, has a relatively long first-feeding phase. Although all species here were maintained and tested at the same temperature, 15°C, there is no evidence that this temperature is optimal for efficient yolk utilization in any of the species studied. Since efficiency of yolk utilisation is known to be temperature dependent (Blaxter, 1969, fig. 6), it is risky to make interspecific comparisons of this kind. That larvae from large eggs (of the same species) better resist pre-first-feeding starvation than larvae from small

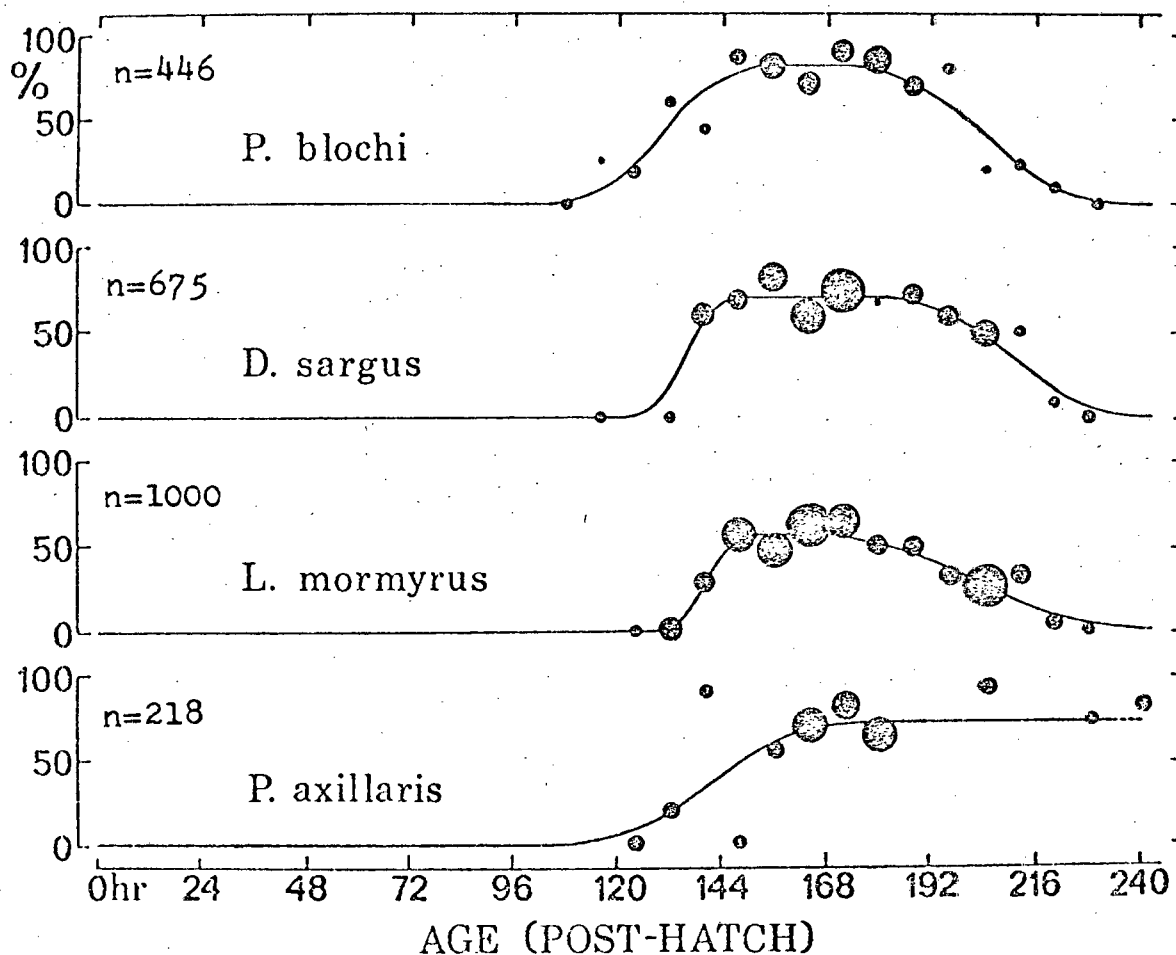


Figure 6. Age-at-first-feeding curves (relating percent of larvae first-feeding during 4-h food-exposure to age of larvae) for Pachymetopon blochi (offered Brachionus), Diplodus sargus (offered Proales), Lithognathus mormyrus (offered Proales), and Pterosmaris axillaris (offered Brachionus). The circles represent raw data; their areas are proportional to the number of larvae tested in the corresponding 8-h age class. The procedure used in fitting the smooth lines is described in the text. A summary of values extracted from these curves may be found in table 2.

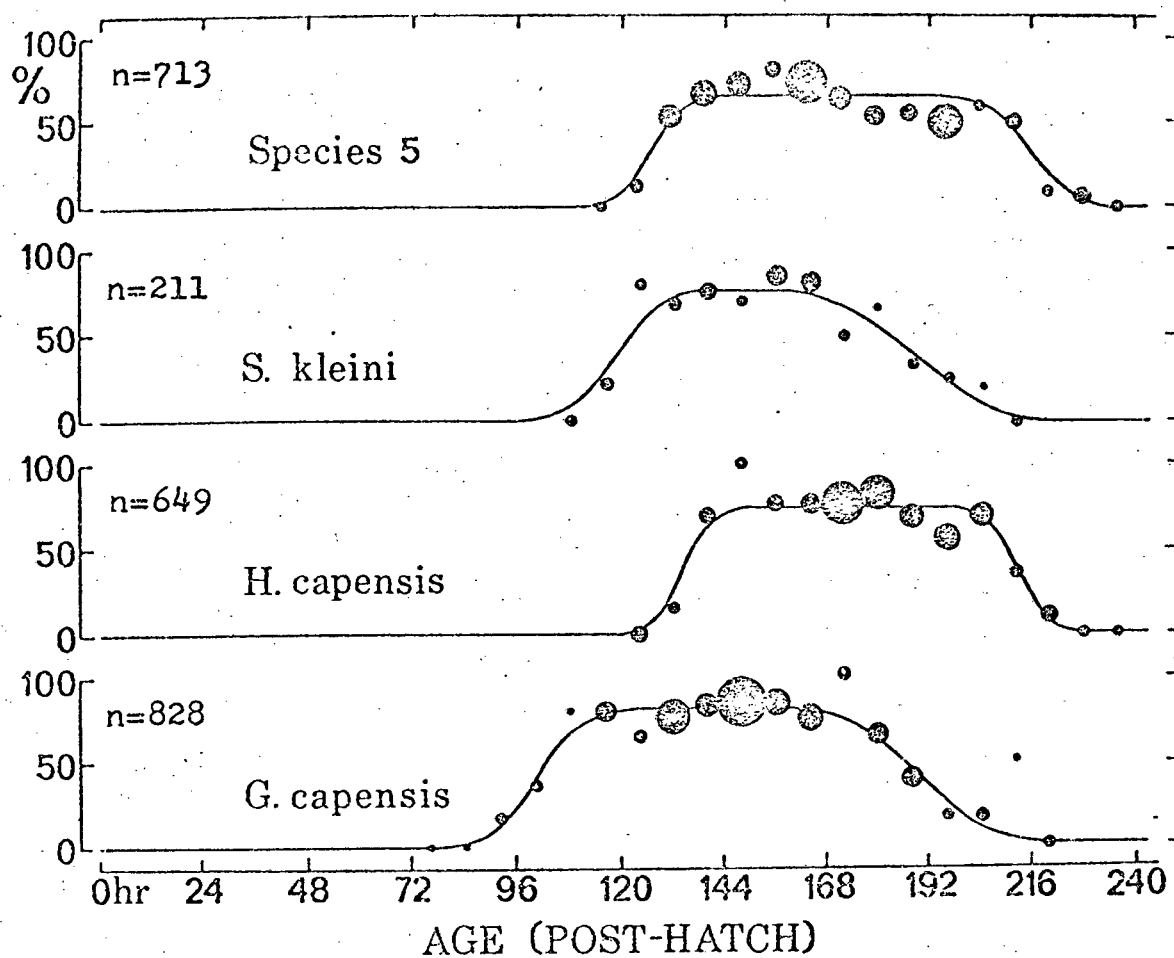


Figure 7. Age-at-first-feeding curves for Species 5 (offered Proales), Synaptura kleini (offered Brachionus), Heteromyceteris capensis (offered Brachionus), and Gaidropsarus capensis (offered Brachionus). See caption of fig. 6 for additional information.

Table 2. Summary of data from age-at-first-feeding curves (eight of which are presented in figs. 6 & 7) for the ten experimental species. Ages in parentheses are estimates: insufficient data were collected to warrant fitting curves. PNR = point-of-no-return (see text).

<u>species</u>	<u>age-at-onset- of-first-feeding</u>	<u>age-at- PNR</u>	<u>age-at-optimal first-feeding</u>
<u>Congiopodus</u> <u>spinifer</u>	(36 h)	(>170 h)	(100 h)
<u>Diplodus</u> <u>sargus</u>	136 h	210 h	173 h
<u>Gaidropsarus</u> <u>capensis</u>	100 h	190 h	145 h
<u>Heteromycteris</u> <u>capensis</u>	134 h	212 h	173 h
<u>Lithognathus</u> <u>mormyrus</u>	140 h	204 h	172 h
<u>Pachymetopon</u> <u>blochi</u>	130 h	204 h	167 h
<u>Pterosmaris</u> <u>axillaris</u>	145 h	(>240 h)	(190 h)
<u>Synaptura</u> <u>kleini</u>	118 h	189 h	154 h
<u>Trulla</u> <u>capensis</u>	(140 h)	(190 h)	(165 h)
Species 5 (Sparidae)	127 h	216 h	172 h

eggs has been demonstrated for Clupea harengus by Blaxter & Hempel (1963). Ciechomski (1966) found practically no such correlation in the Argentine anchovy, Engraulis anchoita.

In first-feeding tolerance testing of larvae from small (<1,25 mm yolk diameter) pelagic eggs at 15°C, one has a leeway of not more than about 24 h on each side of the age-at-optimal-first-feeding in which to test the ability to feed. If one admits to an error of ± 10 h in the determination of the age-at-optimal-first-feeding, the timing of the feeding test is even more critical.

The sense of the expression "point-of-no-return" (PNR) as it is used here is very similar to that first applied by Blaxter & Hempel (1963), i.e., the point reached by previously unfed herring larvae where exposure to food failed to elicit feeding movements. It was distinguished from the point of "starvation" (i.e., death), which occurred some time later. The PNR of Blaxter & Hempel may not be the most relevant starvation threshold for all species. Previously unfed larvae of northern anchovy (Engraulis mordax) (Lasker et al., 1970), haddock (Melanogrammus aeglefinus) (Laurence, 1974), and perhaps turbot (Scophthalmus maximus) (Jones, 1972) reach a point, prior to the PNR of Blaxter & Hempel, where exposure to food still elicits a feeding response, but death ensues regardless. A degeneration of gut epithelium in starving larvae (Umeda & Ochiai, 1975: Seriola) might be involved here. It should, therefore, be noted that, although 50% of larvae in the present study "successfully" first-fed at the PNR, this is no guarantee that subsequent survival could approach 50%, even under optimal conditions.

3.2 Choice of experimental foods, experimental container, density of food, duration of exposure to sub-optimal conditions, and duration of exposure to food

3.2.1 Methods

To aid the selection of effective materials and methods for the tolerance experiments, a number of preliminary trials were required. In general, this involved splitting larvae from any single batch into two or more groups and testing their feeding performance under various conditions.

3.2.2 Results and discussion

3.2.2.1 Experimental foods

Two rotifer species, Brachionus plicatilis and Proales similis, were eventually selected as experimental foods. Several ciliate species, young stages of invertebrates, and non-living foods were also investigated. Some of the observations made on the latter have been included here, in the hope that they will be of interest to other workers. To give an indication of the relative sizes and shapes of the various foods, they have been illustrated, at the same scale, in fig. 8. A newly-hatched Artemia salina is included for comparison.

3.2.2.1.1 Brachionus plicatilis (Müller)

This rotifer (fig. 8b) was isolated from Milnerton Estuary and tested on about 40 species of marine fish larvae. Only eight of the species to which it was offered repeatedly yielded feeding incidences so low as to suggest the unsuitability of the rotifer as first food: Arnoglossus capensis, Engraulis capensis, Lithognathus mormyrus, Sardinops ocellata, Sebastichthys capensis, Trulla capensis, Species 5, and Species 7 (see Part 2 of this thesis for descriptions of these unidentified species). Failure to feed on Brachionus in these cases can be attributed to the small size of the larval mouth. For those larvae that could ingest it, B. plicatilis proved to be an ideal food for testing water quality requirements for first-feeding.

3.2.2.1.2 Proales cf. similis De Beauchamp

Dr. R. Pourriot (Laboratoire de Zoologie, École Normale Supérieure, Paris) wrote (pers. comm., 1977) that this rotifer was "nearly related" to P. similis, by the mastax, long toes, and ringed foot. It is a small (fig. 8c) (total length, extended: 180-200 µm; width: 55-65 µm) brackwater species, also isolated from Milnerton Estuary. It has apparently not previously been cultured as a live food for marine fish larvae. The elliptical eggs (60 X 40 µm) are deposited singly on a substrate, normally algae. Although a certain degree of thigmotaxis is exhibited, the rotifer is, like B. plicatilis, largely pelagic. It was cultured in full-strength sea water.

Feeding incidence on Proales was generally high, and only three of about 40 species to which it was offered failed to feed on it: Congiopodus spinifer and Trigla capensis (a few were ingested by the latter), in addition to ?Conger wilsoni. The rotifer is too small for C. spinifer and T. capensis. In rearing attempts, several species that otherwise might not have survived (Engraulis capensis, Lithognathus mormyrus, Sardinops ocellata, Sebastichthys capensis, and Trulla capensis) were taken well beyond the stage of yolk-sac absorption using Proales.

The methods used here to maintain a constant supply of Proales for experimental purposes must be regarded as preliminary: production varied widely from tank to tank, and could not be consistently correlated with the more commonly monitored, and easily controlled, variables such as pH, turbulence, food (Chlorella) concentration, lighting, salinity, dissolved oxygen, or degree of algal growth on tank walls. Productivity was markedly reduced at temperatures

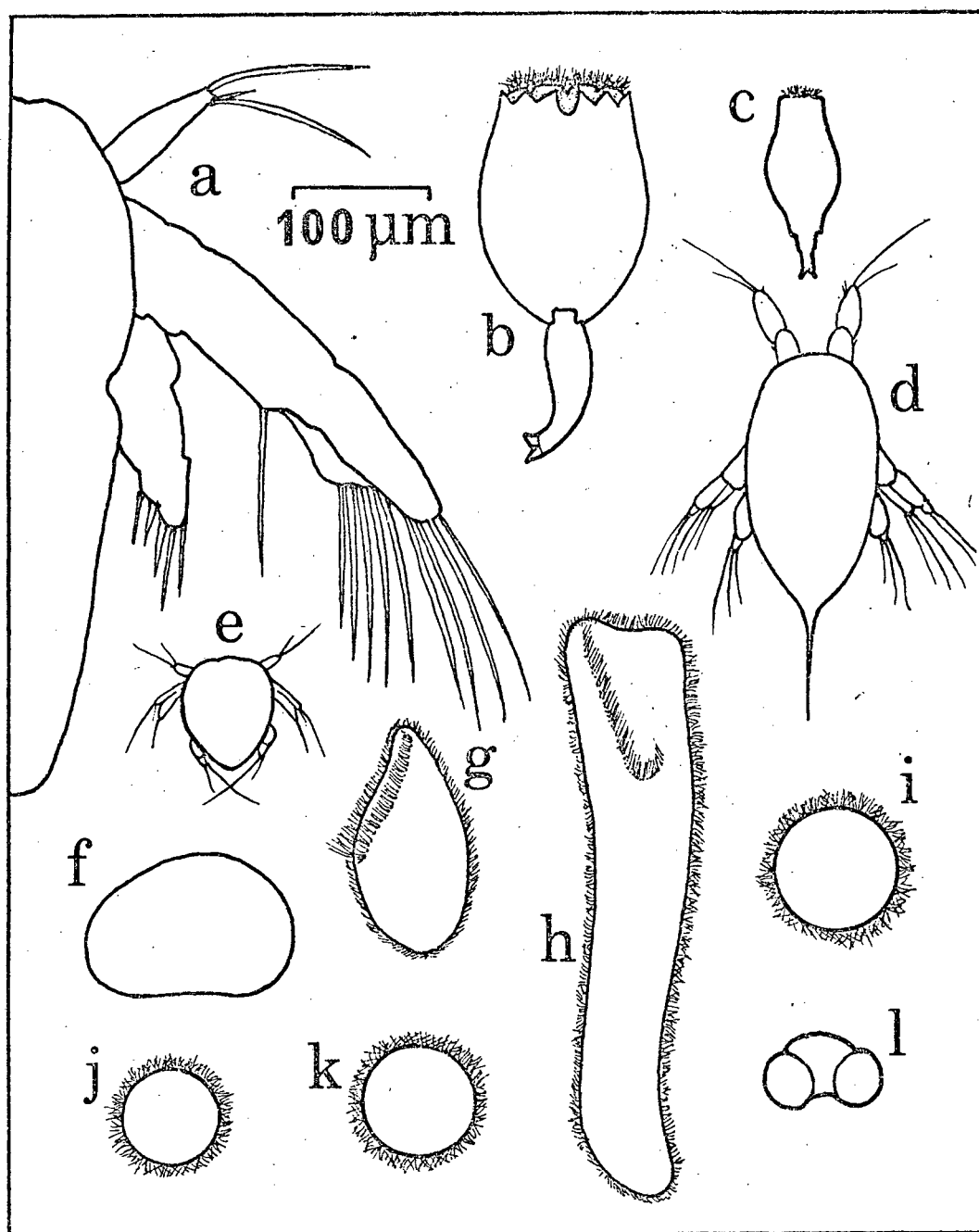


Figure 8. Some of the food types offered to first-feeding larvae in the present study. Particles are drawn to scale. A newly-hatched *Artemia salina* nauplius is included as reference. (a) *Artemia salina*, (b) *Brachionus plicatilis*, (c) *Procales* cf. *similis*, (d) *Pseudodiaptomus hesseli*, (e) *Tisbe* sp., (f) *'Cypridopsis'* sp., (g) *Fabrea salina*, (h) *Condyllostoma* cf. *patens*, (i) *Parechinus angulosus*, (j) *Choromytilus meridionalis*, (k) *Gunnarea capensis*, (l) *Pinus pinaster* pollen.

below about 15°C, but was not much affected (subjective observation) by salinities within the range 10-50‰S, or pH's at least as high as 9.0. Encrusting algae (predominantly blue-greens) on the walls of the culture tanks did not seem to affect productivity until it became very heavy, at which time production of Chlorella was affected as well. It is suspected that the observed fluctuations in rotifer populations were responses to organic metabolites of bacteria, algae, and perhaps ciliates sharing their tanks. The subject deserves attention.

Proales was cultured in a series of up to a dozen 10-litre, all-glass aquaria under a bank of fluorescent and incandescent lights. Every second or third day, 1-2 l of each culture was removed and replaced with filtered, nutrient-rich sea water from a large false-bottom-filter aquarium containing fish. The rotifers in the 1-2 litres removed from each tank were concentrated and examined. Any culture that appeared to be on the decline was discarded, the tank cleaned, and one of the stronger cultures was split in two. The average culture required replacement every 1-2 months.

The population dynamics of these rotifers in culture was studied in two experiments. In the first, a 10-l tank of rotifers, the concentration of which was measured (Coulter Counter) at 42 rotifers ml⁻¹, was dumped out and rinsed, leaving only eggs fixed to algae on the tank walls. The old culture water (pH 8.9) was filtered to remove all rotifers and returned to the tank. Three days later (day 3) there were 28 rotifers ml⁻¹; on day 6 there were 138 ml⁻¹; on day 8, the Chlorella had been removed from the water and the density was measured at 199 ml⁻¹. One may calculate a doubling time (corrected for rotifers removed for counting) between day 3 and day 8 of 42 h. Some of the increase should probably be attributed to continued hatching of the original eggs.

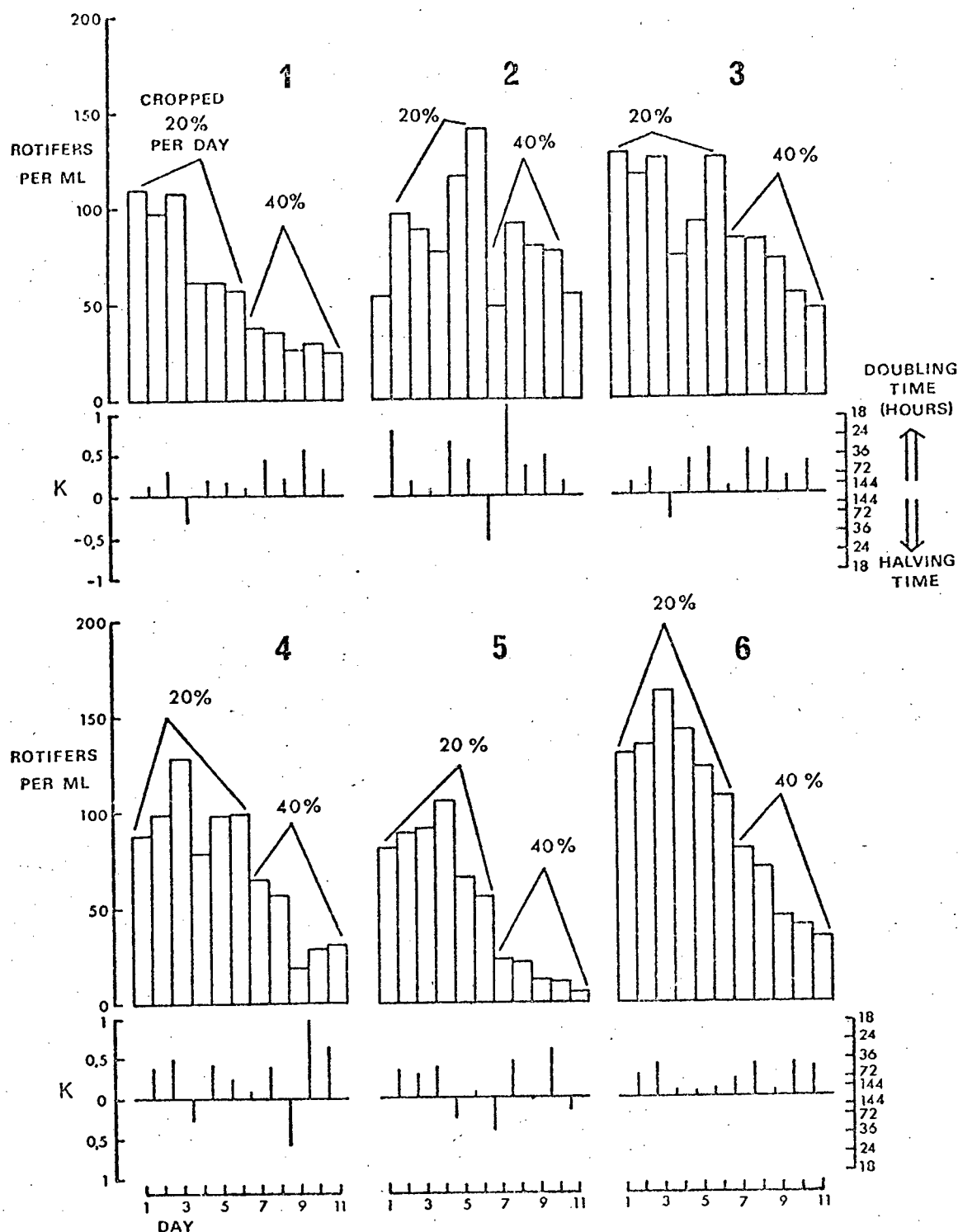


Figure 9. Concentration (rotifers ml⁻¹) and daily instantaneous growth rate (K) of *Proales similis* in each of six 10-l culture tanks over an 11-day period. For the first six days, 20% of the rotifers in the tanks were removed every day, thereafter, 40%. The mean doubling times (i.e. $(\log_e 2)/\bar{K}$) for the six tanks over the 11-day period were 76, 45, 63, 63, 145, and 71 hours.

In the second experiment, the populations in six 10-l culture tanks which had been in operation for several weeks were studied under conditions of daily cropping. Every day for six days, 20% of the rotifers in each tank were removed; for five days thereafter, 40% of the rotifers were removed per day. All but one litre of the filtered culture water was returned to the tanks each day; the litre removed was made up with fish-tank water. Temperature over the 11-day period ranged from 25,5 to 31,5°C, pH from 8,81 to 9,01. The results of these cropping experiments are presented in fig. 9. Under the culture conditions provided, it is clear that growth rate was insufficient to permit 40% day⁻¹ cropping, but that 20% day⁻¹ was not necessarily excessive. Mean doubling time $((\log_e 2)/\bar{K})$ in these six tanks was 68 h (which would have permitted, on average, a cropping rate of 22% day⁻¹, or about 2×10^5 rotifers day⁻¹ tank⁻¹).

The growth rates calculated in these experiments are considerably less than those sometimes reported for Brachionus plicatilis (e.g. Theilacker & McMaster, 1971: doubling times of 19-26 h; Cruz & Millares, 1974, table 1: doubling time of 23 h over first six days). Proales similis was found to be more difficult to culture than B. plicatilis. Any contamination of a P. similis culture with B. plicatilis resulted in a rapid growth of the latter and eventual collapse of Proales.

3.2.2.1.3 Pseudodiaptomus hessei (Mrázek)

This euryhaline calanoid is endemic to southern Africa. The systematics and distribution of the Pseudodiaptomidae were subjects treated in a dissertation by Grindley (1965), parts of which have been published (e.g. Grindley, 1963). The species is very easily cultured through multiple generations in captivity, on a number of foods, including Chlorella, Dunaliella, Phaeodactylum, and baker's yeast. Hart (1973) studied its biology in a South African freshwater lake. Its

congeners, P. euryhalinus and P. coronatus, have been cultured in the U.S.A. (Johnson, 1948; Grice, 1969; Zillioux, in Costlow, 1969:246).

In rearing containers, the adults are largely thigmotactic, spending time perched on tank walls or the air-surface interface; the nauplii (figure 8d) are entirely pelagic, and phototactic. Eggs are carried by the female until hatching.

A 100-l recirculating culture system incorporating a biofilter was devised that automatically separated the nauplii from the other stages. The overflows from a series of six 10-l culture tanks passed through a patch of nylon mesh of 180 μ m pore size built into one wall of each tank. Lighting was maximal near the mesh, with the result that nauplii were drawn into the overflow water and through the nylon screen. The nauplii were then channeled into a partially submerged trap made of 60 μ m mesh where they accumulated.

First-feeding experiments using several species of fish larvae (including Gaidropsarus capensis, Heteromyceteris capensis, and Diplodus sargus) resulted in high percentages of full guts. Observation through the suspended microscope showed, however, that the larvae were feeding almost exclusively on dead or moribund nauplii at the bottom of the containers. They were unable to catch healthy nauplii, which are extremely agile. Although under certain circumstances, this copepod could be of value as an experimental live food, it was unsatisfactory for the present purposes.

3.2.2.1.4 Tisbe sp.

Dr. W. Scheibel (Zoologische Institut und Museum, Universität Kiel) kindly referred this copepod to the genus Tisbe. It was isolated from Milnerton Estuary. Tisbidae are generalized herbivores and detritivores, and have been widely cultured, both experimentally (e.g. Battaglia, 1970) and as food for larval fish (e.g. Alessio, 1974; Hunter, 1976b).

Although this harpacticoid proved to be very useful for rearing larvae in 10-l tanks, the nauplii (fig. 8e) were unsatisfactory for first-feeding experiments in small containers. They tended to congregate at the container floor, and any fish larva that spent too much time resting on the bottom risked being mobbed, and killed, by the nauplii. Girin (1974) recorded lower survival rates among larval turbot (Scophthalmus maximus) reared in the presence of Tisbe.

3.2.2.1.5 "Cypridopsis" (sensu lato) sp.

This ostracod does not appear to be referable to any of the 22 South African species provisionally allocated to this genus by McKenzie (1971). It is a euryhaline species (also isolated from Milnerton Estuary) and was cultured in sea water. The orange eggs are fixed to the substrate, usually along fine crevices. The newly-hatched ostracods (fig. 8f) measure 0,18 X 0,12 mm, which is an acceptable size for many first-feeding larvae. Unfortunately, feeding incidence on ostracods in test containers was generally low, and the same problems experienced with Tisbe occurred with Cypridopsis: congregation at the container floor and mobbing of inactive larvae. Adult ostracods (0,67 X 0,37 mm) were readily taken by advanced sole (Heteromyceteris capensis and Synaptura kleini) larvae and early juveniles. Sparid larvae also consumed the ostracods but they appeared to prefer Tisbe.

3.2.2.1.6 Fabrea salina (Henneguy)

A population of these heterotrichous ciliates (fig. 8g) was discovered in a highly-saline splash pool near Pater-noster, about 200 km north of Cape Town. Based on reported success feeding Fabrea to larvae of gilt-head bream (Sparus auratus) (René, 1974) and seabass (Dicentrarchus labrax) (Barnabé, 1974), it was hoped that the ciliate would constitute a useful experimental live food. The "advantages of this species as an alternative for rotifers or brine shrimp" were listed by De Winter & Persoone (1976:38), who also provided

information on its mass culture.

In controlled experiments with first-feeding Galdropsarus capensis (n=10), Heteromycteris capensis (n=32), and Synaptura kleini (n=2), only a single ciliate was ever taken... by an unfortunate H. capensis. The larva was first sighted with the live ciliate inside its mouth, attempting to eject it; it finally did so some 30 minutes later. Control feeding incidence (Brachionus) for each of the three species of larvae, respectively, was 9 out of 12, 26 out of 30, and 2 out of 2. Fabrea was clearly distasteful to these larvae, and the culture was abandoned.

3.2.2.1.7 Condylostoma cf. patens (Müller)

This heterotrichous ciliate (fig. 8h) was first isolated from a sample of water and sediment from Duncan Docks, Cape Town Harbour, and subsequently found in Milnerton Estuary. Although of a reasonable size for many first-feeding larvae (about 400 X 80 μm), this ciliate has not received as much attention as Fabrea. Kahan (1976) reported, however, that Condylostoma species were under investigation in Israel as a potential live food.

A series of four experiments (two with Heteromycteris capensis, one with Pachymetopon blochi, and one with Diplodus sargus) was conducted to test the relative attractability of Condylostoma and Brachionus. In all cases, feeding incidence among larvae provided with the ciliate was significantly ($p < .05$) less than that among control larvae provided with Brachionus. Unlike Fabrea, however, Condylostoma was ingested in some numbers, with feeding incidence ranging from 0 to 50%. Feeding incidence among control larvae ranged from 73 to 95%. One of the H. capensis experiments was continued for three days beyond the initial 4-h test. Larvae were transferred daily to other containers holding fresh system water and food. There was no mortality in the control group, and all larvae (n=21) had food in their guts at the end of the experiment. Mortality in the Condylostoma group was 30% (n=20) and only a single larva had food in its gut at the end of the experiment. One must conclude that either the

nutritional value of the ciliate was unsatisfactory or that, because of their relatively low attractability, the larvae failed to ingest adequate numbers of them.

3.2.2.1.8 Marine invertebrate larvae

Larval stages of assorted echinoderms, molluscs, and annelids have been found among the gut contents of fish larvae at sea (e.g. Lebour, 1920). Their use in laboratory rearing attempts was reviewed by May (1970), who cited 16 publications where eggs or larvae of these invertebrates were offered, with varying degrees of success, to marine fish larvae. In the SW Cape Province, sexually ripe individuals of the intertidal polychaete, Gunnarea capensis (Schmarda), and the urchin, Parechinus angulosus (Leske), are available all year; ripe black mussel, Choromytilus meridionalis (Krauss), are available in spring (October-November).

Because of their pale, red-brown colour, the first free-swimming stages of P. angulosus (fig. 8i) and C. meridionalis (fig. 8j) were very difficult to detect in the gut; Gunnarea trochophores (fig. 8k), on the other hand, being white, were readily discernible. Incidence of first-feeding on all three species was almost always significantly ($p < .05$) below that on rotifers. The exception was a trial in which 34% of a group ($n=38$) of Trulla capensis larvae offered Gunnarea fed, and 53% of the control group ($n=36$) fed, the difference being non-significant.

3.2.2.1.9 Non-living foods and non-foods

The attractability of three kinds of non-living particles was compared to that of live rotifers. Four trials were conducted, two with the soleid, Heteromycteris capensis, one with the sparid, Lithognathus mormyrus, and one with the cynoglossid, Trulla capensis. The larvae were about equally distributed among four test containers, each with a different "food". Pulverized commercial aquarium food (TetraMin baby fish food "E") which had been suspended in sea water, then passed through a 100 μ m nylon screen, and trapped on a 40 μ m screen, was given to one group. A freeze-dried, fat-extracted preparation (provided by Mr.

Victor G. Langridge of Fishing Industry Research Institute, Univ. of Cape Town) of yeast (Candida lipolytica) grown on fish-oil wastes (Langridge & Templar, 1977) was similarly size-graded and offered simultaneously to the second group. The third group received a suspension of pine (Pinus pinaster) pollen (fig. 91). The pollen had been collected from male cones, cleaned of debris by screening, and stored dry. Most of the buoyancy of the pollen was eliminated before use by suspending some of it in about 20 ml of water which was rapidly brought to the boiling point. Brachionus or Proales served as the control food. Table 3 compares feeding incidences recorded for the control foods and the three test preparations.

Table 3. first-feeding incidence of three species of larvae offered size-graded aquarium-fish food, or size-graded yeast preparation, or pine pollen. Control food for H. capensis was Brachionus; control food for L. mormyrus and T. capensis was Proales. Exposure to food lasted 4 h. Most of these data were previously published by Langridge & Templar (1977).

food	<u>Heteromyceteris</u> <u>capensis</u> (Soleidae)*		<u>Lithognathus</u> <u>mormyrus</u> (Sparidae)		<u>Trulla</u> <u>capensis</u> (Cynoglossidae)	
	n	% fed	n	% fed	n	% fed
TetraMin	42	41	55	36	32	47
yeast	44	59	41	27	35	29
pollen	29	89	40	73	36	75
control	41	83	56	77	26	46

*results of two trials with the Cape sole are combined here

If the data obtained from the four trials are pooled, the ratio of larvae feeding on TetraMin becomes 52/129 (40%); yeast, 47/120 (39%); pollen, 82/105 (78%); and rotifers, 89/123 (72%). Feeding incidence on TetraMin or yeast was

significantly less ($p < 0.001$; Chi-square test) than that on pollen or rotifers. Although pollen was ingested at least as frequently as live rotifers, larvae (Heteromyceteris capensis) feeding on it survived the same length of time as larvae in containers without food. It was ingested by 15 of 16 species to which it was offered (the exception being a small ($n=4$) group of Engraulis capensis). Lasker (1977) has noted, based on analysis of gut contents, that scup (Stenotomus chrysops) larvae in the New York Bight selected pine pollen from the plankton. Its concentration in the Bight was 10-40 pollen grains per cubic metre.

The attractability of pollen to many species of small-mouthed larvae, its availability, and its ease of storage make it a useful experimental tool for behavioral studies on the response of larvae to non-motile foods. In fact, if a micro-encapsulated particle could be made to mimic pine pollen—or, if pine pollen could be rendered nutritious, one would have an ideal particulate food.

3.2.2.2 Experimental container

A few species yielded very low first-feeding incidences in the 350-ml test containers, but fed well in 10-l aquaria. Such species were predominantly those with an elongated body, e.g. the clupeids, Etrumeus and Sardinops; engraulid, Engraulis; ophidiid, Xiphiurus; carapid, Species 1; and cheilodactylid, ?Cheilodactylus. Practically all the shorter-bodied larvae, e.g. the sparids, soleids, gadid (Gaidropsarus), callionymid (Paracallionymus), fed about equally well in 350 ml as in 10 l. Apparently the accuracy of the S-flexure feeding strike of the more elongated larvae is particularly impaired by proximity to solid surfaces. In order to conserve system water, a small container was desirable; those species that first-fed poorly in 350-ml containers were simply not used for tolerance testing.

3.2.2.3 Density of food

First-feeding Diplodus sargus ($n=130$) and Gaidropsarus

capensis ($\Sigma n=115$) were used to obtain an indication of the density of Proales and Brachionus, respectively, required for the first-feeding tolerance tests. In each case, an array of five 350-ml feeding containers were filled with system water to which rotifers were added to yield final concentrations of 5, 10, 20, 40, and 80 rotifers per ml. In the case of D. sargus feeding on Proales, the highest feeding incidence (79%, 20 rotifers per ml) did not differ significantly ($p=.05$) from feeding incidences recorded for 10, 40, or 80 rotifers per ml. The feeding incidence at 5 rotifers per ml (26%) was both significantly less than that at 20 per ml, and significantly less than the mean feeding incidence for the other four concentrations. In the case of G. capensis feeding on Brachionus, the highest feeding incidence recorded (91%, 40 rotifers per ml) did not differ significantly from the lowest (63%, 5 per ml). Based on these and other considerations, a rotifer density for both Proales and Brachionus of 15 (10-20) per ml was selected for use in first-feeding tolerance tests.

3.2.2.4 Duration of exposure to sub-optimal conditions

Twenty-four hours (rather than 48, 96, or even the entire interval between hatching and first-feeding) was chosen as the standard duration of exposure to sub-optimal conditions. The rate of development of fish eggs and larvae is very often altered—sometimes accelerated, usually retarded—under adverse conditions. Rosenthal & Alderdice (1976:2056) reviewed several publications where such effects were recorded for marine teleost eggs and larvae; many more examples are available in the freshwater literature. Because timing of the first-feeding test was so critical in the present study, any differential developmental acceleration or retardation between control and treatments, or even between treatments, would have greatly complicated the interpretation of results. No attempts were actually made here to detect or quantify developmental rate effects resulting from the variables

studied. It was assumed that a 24-h exposure would sufficiently effect first-feeding incidence to provide a useful indication of tolerance, and at the same time cause minimal alteration of the age-at-optimal-first-feeding.

3.2.2.5 Duration of exposure to food

The choice of 4 h as a standard period of exposure to food was based on experiments with four species (the results of which are presented in fig. 10). Larvae were placed in

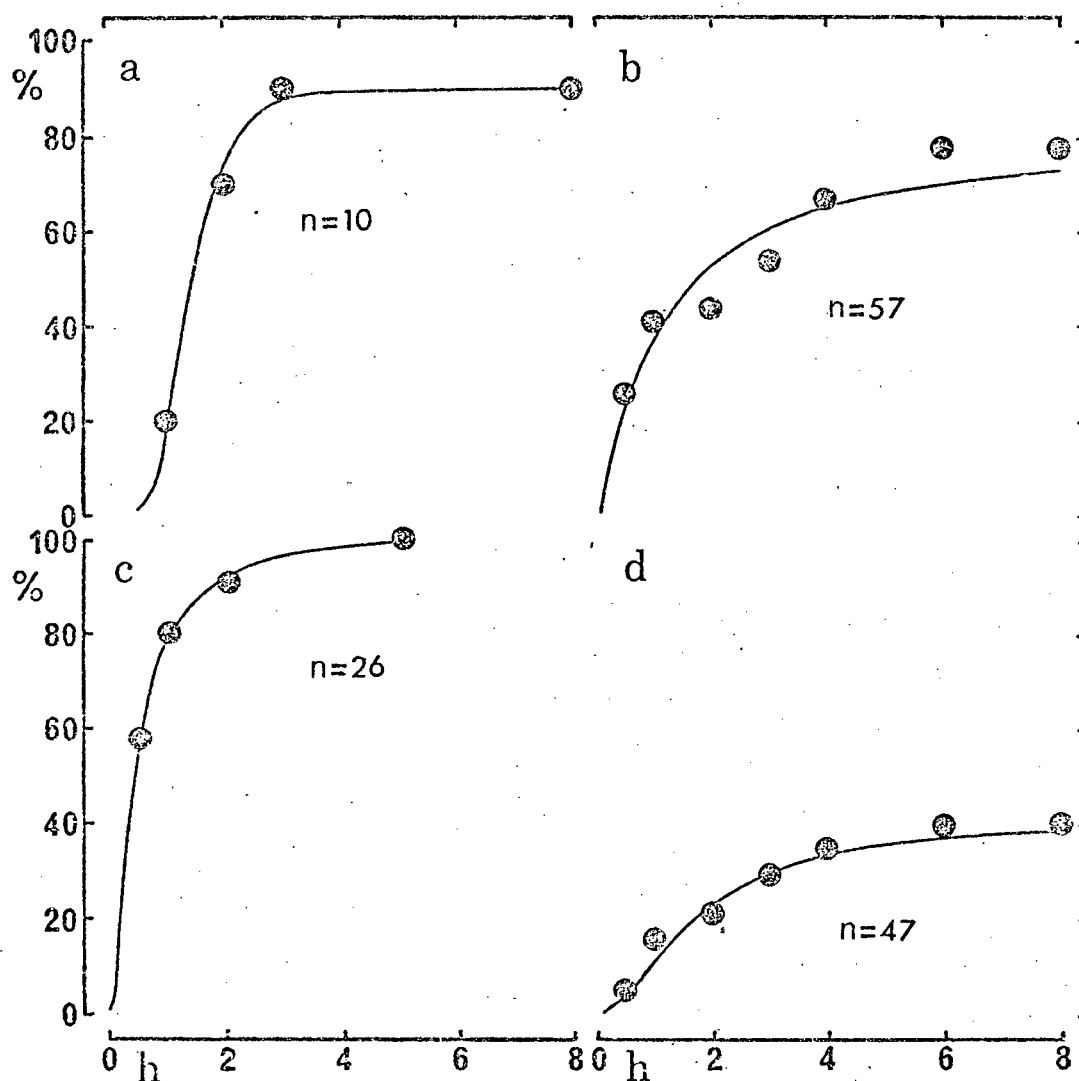


Figure 10. Percent feeding incidence plotted against time of exposure to food. The smooth curves are least-square fits of adjusted (Abbot's formula) feeding incidence, transformed to probit versus logarithm of time. (a) *Diplodus cervinus*, offered *Brachionus*; (b) *Diplodus sargus*, offered *Proales*; (c) *Gaidropsarus capensis*, offered *Brachionus*; and (d) *Lithognathus mormyrus*, offered *Proales*.

350-ml containers with system water, plus an appropriate rotifer food, left at least 30 min, transferred to other containers, also with food, and back, etc. At each transfer the number of larvae earning a rating of "fed" was recorded. Feeding incidence reached a maximum by the third hour in the case of Diplodus cervinus; the fifth hour, Gaidropsarus capensis; and the sixth hour, Diplodus sargus and Lithognathus mormyrus. Although the tests were extended to a total of eight hours (except the G. capensis test, in which 100% of the larvae had fed within 5 h), there was no further increase in first-feeding incidence. Based on the curves fitted to the data, 90% of the larvae that had fed by 8 h would be expected to already have fed by 2,3; 5,8; 1,6; and 4,9 h for the four species (a-d) of fig. 10, respectively. The 4-h food exposure used in subsequent tolerance testing approximates the mean of these four values (3 h 40 min) and roughly marks the beginning of the asymptotic portion of the curves.

4. TOLERANCE STUDIES

4.1 General methods

The tolerance of marine fish larvae to various sub-optimal conditions was assessed on the basis of two responses -- one sub-lethal, termed here the first-feeding EC50; one lethal, the well-known, LC50. The following presentation of methods has been organized after the seven points of Cairns' (1969) "rating system" for publications on the toxicity of substances to aquatic organisms:

- 1 - Test organisms clearly identified as to species, size, and weight.
- 2 - Dilution water quality stated.
- 3 - Bioassay organisms pre-conditioned or acclimated to test environment.
- 4.- Methods and procedures clearly stated.
- 5 - Appropriate controls included.
- 6 - Adequate control of environmental conditions.
- 7 - Statistical evaluation of data.

Test organisms

Three major constraints were imposed on the choice of species for these tests: 1) availability of eggs in the plankton, 2) high survival under prevailing laboratory conditions, and 3) satisfactory (at least 50%) feeding incidence at age-of-optimal-first-feeding under prevailing conditions. Ten species satisfied these requirements; they are listed in Table 2, along with certain other information relevant to these tests.

Dilution water

In all tests, the dilution water came from the closed-circulation system described previously. Some features of this water have been presented in Table 1.

Acclimation of organisms

The experimental temperature, 15°C, is a rough compromise between the colder temperatures usually recorded on the Atlantic side of the Cape Peninsula and the warmer tempera-

tures usually recorded in summer in False Bay. (see Brown & Jarman, 1978). It may not be the optimal temperature for development through the first-feeding stage for the ten species used in the tests. The fact that first-feeding incidence was consistently high among these species suggests, however, that neither the temperature nor the other experimental conditions were excessively inhibitory.

The food organisms (rotifers) used in feeding tolerance experiments underwent no acclimation, either to system water or to the presumably sub-optimal conditions prevailing in treatment containers. The assumption made here was that the availability and attractability of the rotifers as food for larvae were not significantly affected by the test solutions. In fact, no differences in the distribution of rotifers in the control and various treatment containers were detectable by eye. It would appear that even the degree of phototaxis and thigmotaxis expressed by the roti-

Table 4. Maximum and minimum ages (post-hatch) at which the ten species of larvae were exposed to test water, and the rotifer used as experimental food.

species	age at beginning of 24-h exposure to test water	age at beginning of 4-h exposure to food	experimental food
<u>Congiopodus spinifer</u> (spinenose horsefish)	62 - 86	86 - 110	<u>Brachionus</u>
<u>Diplodus sargus</u> (blacktail)	135 - 159	159 - 183	<u>Proales</u>
<u>Gaidropsarus capensis</u> (Cape rockling)	107 - 131	131 - 155	<u>Brachionus</u>
<u>Heteromyceteris capensis</u> (Cape sole)	135 - 159	159 - 183	<u>Brachionus</u>
<u>Lithognathus mormyrus</u> (sandsteenbras)	134 - 158	158 - 182	<u>Proales</u>
<u>Pachymetopon blochi</u> (hottentot)	129 - 153	153 - 177	<u>Brachionus</u>
<u>Pterosmaris axillaris</u> (windtocy)	152 - 176	176 - 200	<u>Brachionus</u>
<u>Synaptura kleini</u> (lace sole)	116 - 140	140 - 164	<u>Brachionus</u>
<u>Tralla capensis</u> (sand tonguefish)	127 - 151	151 - 175	<u>Proales</u>
Species 5 (Sparidae) (unidentified)	134 - 158	158 - 182	<u>Proales</u>

fers was not noticeably affected by the test concentrations employed.

Methods stated

Larvae to be used in tolerance tests were pipetted from their larva baskets approximately 26 h prior to the calculated age-at-optimal-first-feeding for that species (table 4). A kind of randomness in apportioning available larvae to control and treatment test containers was achieved by very gently stirring the water in the floating basket, then drawing out a few larvae at a time, filling all the containers more or less simultaneously. The containers were then closed with the screened bung, turned on their sides, and left undisturbed in the end of the water table adapted for use as a water bath. After 24 h, containers were removed from the water table and placed on a black stand under fluorescent lighting providing 3000 lux at the level of the containers. A count was made of mortalities (with death defined as a whitening of the tissue) with the aid of the suspended microscope. A concentrated suspension of rotifers was then distributed about equally among the containers, without removing the screened bung, to yield a final concentration of 15 (10-20) rotifers per ml. By withdrawing the bung just far enough to trap the additional fluid, the container could once again be turned on its side without leaking. Exposure to food lasted 4 h. Finally, the containers were righted, bung removed, and larvae were examined with the suspended microscope, evaluated according to the gut-fullness rating system described above, and removed one at a time by pipette. For various reasons, the methods used in certain tolerance tests were more complex than those just described (see "specific methods" below).

Controls

When large hauls of eggs were taken in the plankton, there were sometimes sufficient numbers of larvae hatching during a single 12-h interval to make up an entire treat-

ment series plus control. When material was less abundant, one or more of the planned treatment tests were dropped, and those tests were completed with larvae from another 12-h interval, or even from another collection of eggs. No tolerance tests were conducted, however, without simultaneous controls, consisting of larvae taken in the same collection and hatched during the same 12-h interval as the treatment larvae.

Feeding incidence in control groups usually varied, sometimes quite noticeably, from one batch to another. A series was rejected whenever control feeding incidence fell below an arbitrary 50%. Batches with different control feeding incidences were rendered comparable by making the assumption that, for any one species, the percent decrease in feeding incidence in treatment groups (relative to the control group) is strictly a function of the concentration of inhibiting substance, and is not related to the incidence of feeding in the control group. In fact, based on correlation analyses of cases where the same concentration of inhibitor was tested on more than one batch of the same species, the assumption may be justified: there was no statistical evidence that batches in which first-feeding incidence was high in the control group fed disproportionately better under sub-optimal conditions in treatment groups.

When combining data from different batches, a weighted, mean feeding incidence was calculated for the controls:

$$\bar{p}_c = \frac{\sum p_c n_c}{\sum n_c} ;$$

and for any treatment concentrations where data from more than one batch were combined:

$$\bar{p}_t = \frac{\sum \frac{p_t^* n_t}{p_c}}{\sum n_t} ;$$

where p_c = proportion of larvae feeding in control group
 n_c = number of larvae tested in control group
 p_t^* = proportion of larvae feeding in treatment group (The asterisk indicates (Finney, 1971: 125) that the proportion has not been corrected for natural responsiveness.)
 n_t = number of larvae tested in treatment group.

Note that the term, $\frac{p_t^* n_t}{p_c}$, corrects each batch inde-

pendently for natural responsiveness, but that n_c should be at least as large as n_t , in order that the error arising from an imprecise estimation of the natural response rate ($C = 1 - \bar{p}_c$) be minimized. The natural response rate, C , allows one to assign corrected weighting coefficients when the treatment data are linearized and when confidence limits are calculated. The value, $\bar{p}_t$, was used as an estimate of the mean feeding incidence at a particular treatment concentration.

Environmental conditions

Tolerance tests were conducted in the same constant-temperature room that housed the closed-circulation system. Light intensity was 300 lux where the 24-h exposures were conducted and 3000 lux where the 4-h feeding tests were conducted. Lights were kept on 24 h a day throughout development and testing, the idea being to minimize environmental cues the larvae may use to establish diurnal feeding rhythms. Feeding tests were often run during hours of natural darkness.

Feeding inhibition due to various kinds of operator interference (door-slamming, shadows passing over containers, etc.) was found to be short-lived among very young larvae, and very unlikely to be a significant source of error.

Statistical evaluation

A method for reducing raw, quantal response data to response curves was taken from Finney (1971). The procedure

involves fitting a straight line to the plot of response rate, converted to probits, against concentration of the test variable, usually (but not always) converted to logarithms. The fit is achieved with a weighted linear regression analysis employing maximum likelihood estimation, and it may be improved by successive iteration. Corrections were made to weighting coefficients to account for natural responsiveness (Finney, 1971, chpt. 7). The estimation of the natural response rate (C) was based entirely on control response, as was described above. All computations were made on a HP-65 programmable calculator, with the aid of tables provided by Finney.

As an aid to interpretation of the response curves, probits were retransformed to percentages, and logarithms (when used) to their antilogarithms before the curves were graphed. In most data sets, treatments were too few in number to permit dependable assessment of heterogeneity. All confidence limits have, therefore, been calculated without heterogeneity coefficients, even when the data could arguably be considered heterogeneous. For this reason, the 95% intervals presented should not unreservedly be accepted as accurate, in the strictest statistical sense—they do provide a good indication of the variability encountered in these experiments—and this is their intended purpose.

For each combination of fish species and variable tested, four values, with their respective 95% confidence limits, were extracted from the calculated response curves: 1) 24-h LC50 (concentration of the variable that kills 50% of the larvae during a 24-h exposure), 2) 24-h LC10 (concentration that kills 10%), 3) 24-h first-feeding EC50 (concentration that reduces first-feeding incidence by 50% after a 24-h exposure), 4) 24-h first-feeding EC10 (concentration that reduces first-feeding incidence by 10%).

4.2 NH_3

4.2.1 Specific methods

Known volumes of a concentrated (4,19 M) NH_4Cl solution, measured by micropipette, were mixed with freshly-drawn system water to yield a graded series of test solutions. Since NH_4Cl in solution is a weak acid, there is a decrease in the resulting pH of treatment solutions as increasing amounts of NH_4Cl are added. The proportion of ammonia in the un-ionized form was, therefore, calculated independently for each treatment, based on the pH (NBS) measured after larvae were removed from test containers. A value for the dissociation constant of NH_4^+ at 15°C , ionic strength 0,7 (=34 %S), 1 atm pressure, was provided by Whitfield (1974, table 10): $\text{pK}_a^S = 9,67$. This value remains virtually unchanged when adjusted to 35%S (by multiplying by the slope of the regression of pK_a^S on ionic strength, from column A† of Whitfield's table 3). Whitfield (1974) originally assigned an uncertainty of $\pm 0,03$ pK units to his values. He subsequently (Whitfield, 1978) reduced this estimate of error to $\pm 0,01$ units.

The 95% confidence limits presented with the ammonia response curves have been expanded by a value of 8% of the predicted mean effective concentration at any response percentile in order to account (in an approximate way) for uncertainty in the true concentrations of un-ionized ammonia to which larvae were exposed. About 70% of the uncertainty arises from pH instrumentation error and error in the ionization constant of ammonium; the rest is due to error in preparation of stock solution, micropipette error, and variation in un-ionized ammonia concentration during the course of the exposure. Response curve calculations were based on a log/normal model of tolerance distribution.

4.2.2 Results and discussion

The results of the ammonia experiments are presented in fig. 11 and table 5. They concern five species: the gadid, Gaidropsarus capensis, and the four sparids, Diplodus sargus, Lithognathus mormyrus, Pachymetopon blochi, and the un-identified Species 5.

The most sensitive species appears to be D. sargus, where a 24-h exposure to a concentration of $0,10 \text{ mg l}^{-1} \text{ NH}_3\text{-N}$ (un-ionized) would be expected to reduce first-feeding incidence by 50%. The most tolerant was P. blochi, with a first-feeding EC50 of $0,22 \text{ mg l}^{-1}$. The concentration that decreased first-feeding incidence by 10% (the EC10) ranged from 0,03 (95% limits: 0,01-0,08) in the case of D. sargus, to 0,13 (0,10-0,16) in the case of P. blochi. The 24-h LC50's for the four perciform species fell between 0,36 and $0,42 \text{ mg l}^{-1}$; the gadid yielded a slightly higher value: $0,46 \text{ mg l}^{-1}$. These concentrations may be seen in perspective with the aid of table 5, where the results of some other studies are assembled.

Aside from the study on 6-11 mm guppies (Poecilia reticulata) by Rubin & Elmaraghy (1977), the only available data, to the author's knowledge, on the tolerance of fish eggs and larvae to ammonia is from work on trout (several such studies mentioned by EIFAC, 1970, in addition to Rice & Stokes, 1975: Salmo gairdneri; Burkhalter & Kaya, 1977: S. gairdneri; Thurston et al., 1978: S. clarki), which, of course, have an early life history very unlike that of pelagic marine forms. In general, trout eggs can tolerate quite high levels of ammonia. Yolk-sac stages are very tolerant (Rice & Stokes, 1975), to very sensitive (Burkhalter & Kaya, 1977). Only part of the contrast between these two publications can reasonably be attributed to differences in duration of exposure. Guppy fry were less tolerant than adult male guppies, but still within the typical range for freshwater fish (96-h LC50= $1,24 \text{ mg l}^{-1} \text{ NH}_3\text{-N}$ (un-ionized)) (Rubin

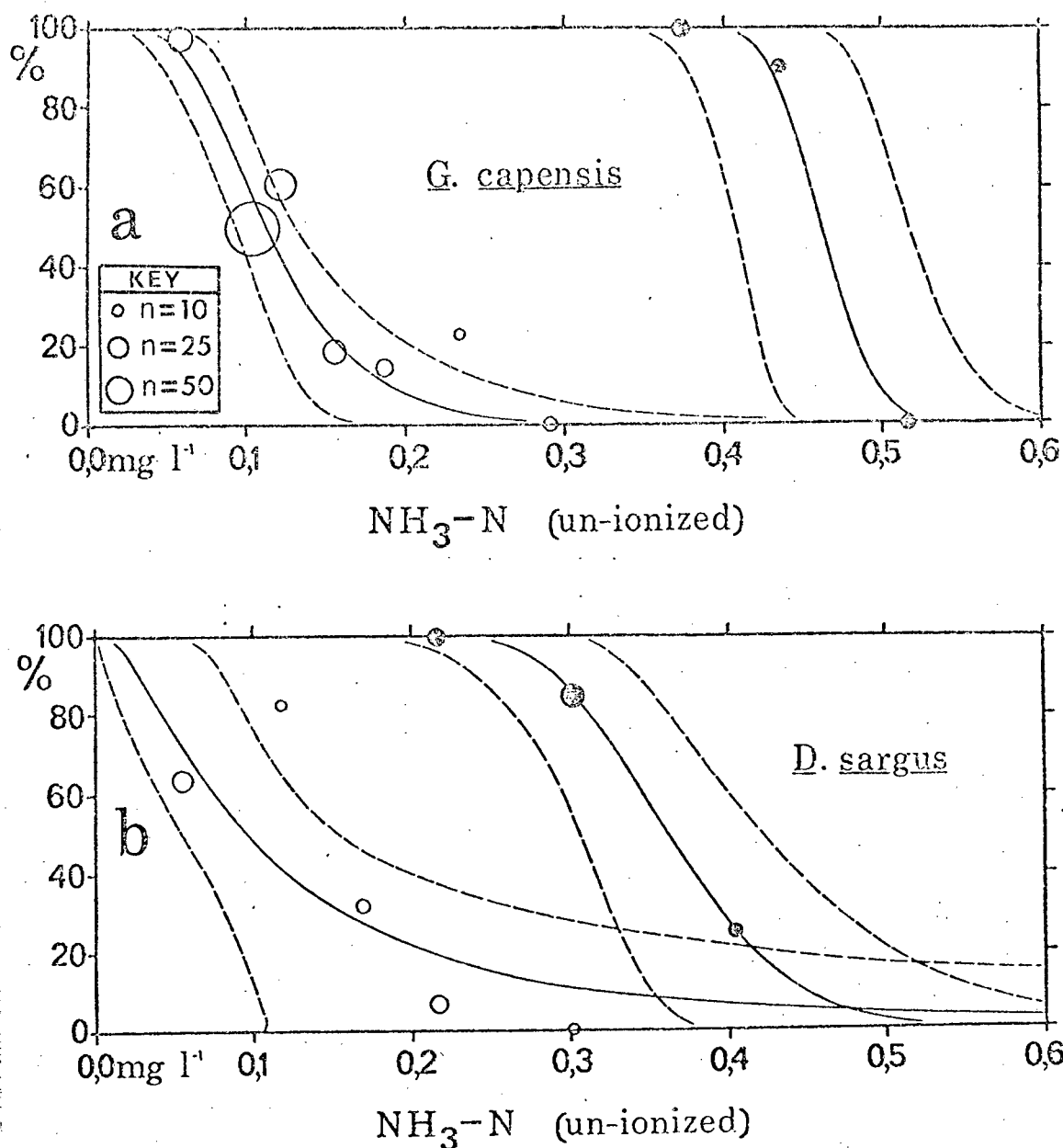


Figure 11. Response of first-feeding (a) *Gaidropsarus capensis*, (b) *Diplodus sargus*, (c) *Lithognathus mormyrus*, (d) *Pachymetopon blochi*, and (e) Species 5 to un-ionized ammonia. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various ammonia concentrations. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding ammonia concentrations. The key included in fig. 12a applies to these and all subsequent response graphs. The solid curves were fitted by assuming a log/normal distribution of tolerance. 95% confidence limits are represented by dashed lines.

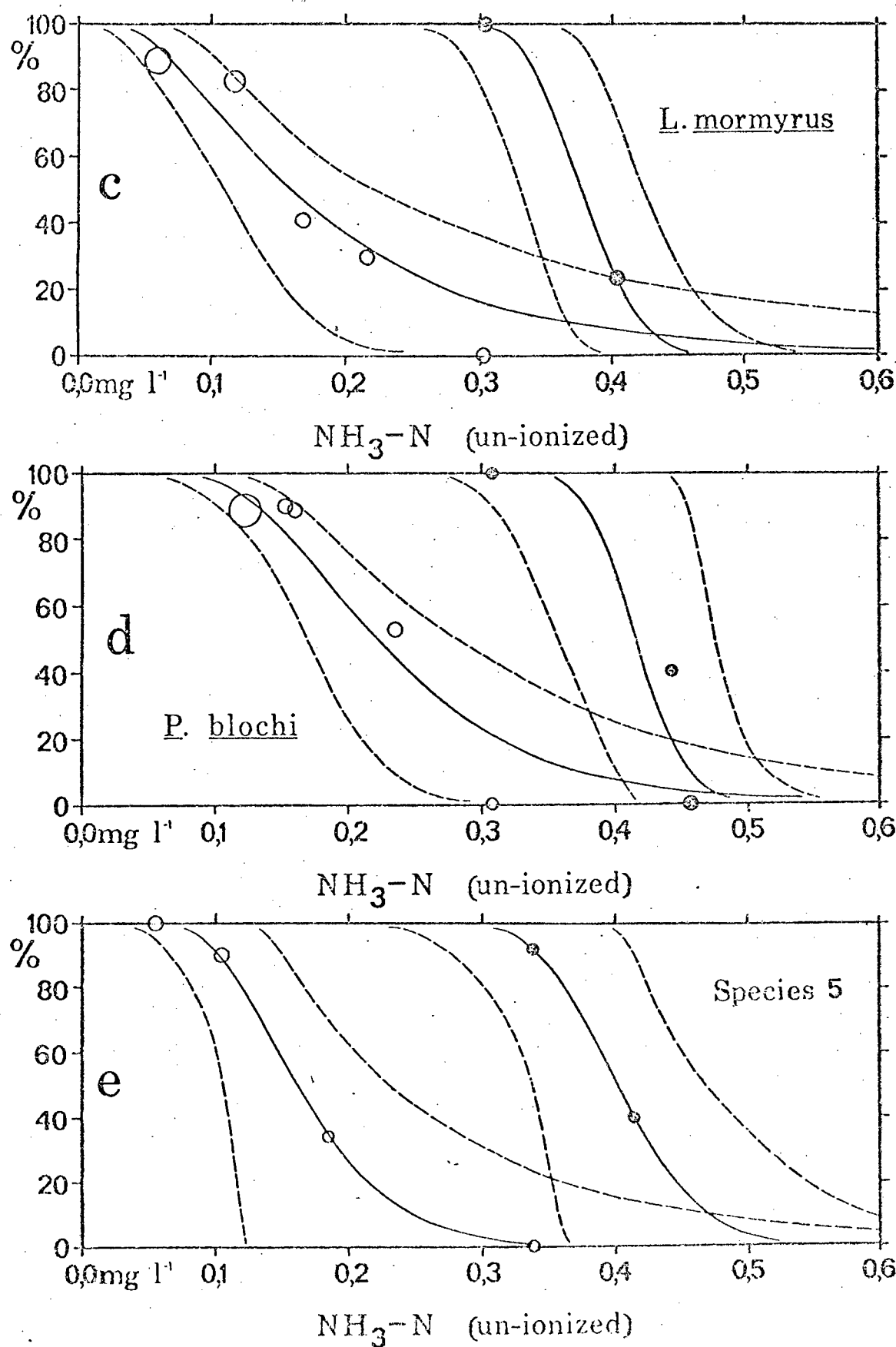


Figure 11. (continued)

Table 5. Selected data on the response of some freshwater and marine teleosts to un-ionized ammonia. (A) Lethal effects on juveniles and adults. (B) Lethal effects on eggs and larvae. (C) Feeding and growth effects.

un-ionized ammonia-N concentration (mg l ⁻¹)	species	stage in life history exposed	salinity	temp. (°C)	pH	response	source of ammonia	reference
	A. Freshwater and marine fish: lethal effects on juveniles and adults							
3,1	<u>Ictalurus punctatus</u> (channel catfish)	Juvenile	fresh water	30	8,6-8,8	96-h LC50	NH ₄ Cl	Colt & Tchobanoglous, 1976
2,4	"	"	"	25	8,5-8,9	24-h LC50	"	Robinette, 1976
1,1	<u>Gambusia affinis</u> (mosquitofish)	adult	"	21-22,5	7,75-7,85	asymptotic LC50 ¹	"	Hemans, 1966
0,68 ²	<u>Morone saxatilis</u> (striped bass)	Juvenile	"	23	7,4-8,0	96-h LC50	"	Hazel et al., 1971
0,65 ²	<u>Gasterosteus aculeatus</u> (stickleback)	Juvenile or adult	"	23	7,0-7,3	96-h LC50	"	"
0,45 ²	<u>Salmo gairdneri</u> (rainbow trout)	Juvenile	fresh water	13,6	7,45	24-h LC50	"	Herbert & Shurben, 1965
0,98 ²	"	"	10‰ S	"	"	"	"	"
0,46 ²	"	"	36‰ S	"	"	"	"	"
0,41 (0,36-0,47)	<u>Abramis brama</u> (bream)	"	fresh water	9,4-14,6	7,8-8,1	asymptotic LC50 ¹	"	Ball, 1967
0,35 (0,30-0,40)	<u>Rutilus rutilus</u> (roach)	Juvenile	"	10,0-13,3	7,8-8,3	"	"	"
0,29 (0,24-0,34)	<u>Perca fluviatilis</u> (perch)	Juvenile	"	9,4-11,1	7,8-8,1	"	"	"

footnotes: 1. As defined by Brown (1971), i.e., the concentration at which the LC50 becomes effectively constant for some prolonged period of time.

2. Values taken from these publications were recalculated in light of more modern ammonium dissociation constants. The constants used were the following: pK_a (0% S, 23°C)=9,31; pK_a (0% S, 13,6°C)=9,61; pK_a (10% S, 13,6°C)=9,64; pK_a (36% S, 13,6°C)=9,71. They are based on pK_a values from Emerson et al. (1975) corrected for ionic strength (Whitfield, 1974).

Table 5. (continued)

un-ionized ammonia-N concentration (mg l ⁻¹)	species	stage in life history exposed	salinity	temp. (°C)	pH	response	source of ammonia	reference
B. Freshwater and marine fish: lethal effects on eggs and larvae								
2.95	<i>Salmo gairdneri</i> (rainbow trout)	fertilized eggs and yolk-sac larvae	fresh water	10	8.3	24-h LC50 exceeded this concentration	(NH ₄) ₂ SO ₄	Pice & Stokes, 1975
1.47	"	gametes	"	8-10	"	no noticeable decrease in fertilization success when eggs were artificially fertilized in water of this concentration	"	"
0.06	"	25 d after yolk-sac absorption	"	10	"	24-h LC50	"	"
1.47	<i>Poecilia reticulata</i> (guppy)	6-11 mm total length	"		6.95- 7.50	24-h LC50	NH ₄ Cl	Rubin & Elmaragby, 1977
0.37	"	24 h post- fertilization to hatching	"	10 & 12	7.4-7.6	no effect on egg survival or incubation time	NH ₄ Cl	Burkhalter & Kaya, 1977
0.25	"	24 h post- fertilization to 21 days post-hatch	"	10 & 12?	"	cumulative mortality of 50% (relative to control) during time period stated	"	"
0.05	"	"	"	"	"	mean total length of 21-d post-hatch larvae was sig- nificantly (P, 0.05) less than that of control	"	"
0.46 (0.41-0.52)	<i>Gaidropsarus capensis</i> (Cape rockling)	first-feeding larva	sea water	15	7.7-7.8	24-h LC50	"	(this study)
0.42 (0.36-0.48)	<i>Pachymetopon blochl</i> (hottentot)	"	"	"	"	"	"	"
0.40 (0.34-0.47)	Species 5 (unidentified)	"	"	"	"	"	"	"
0.38 (0.33-0.42)	<i>Lithognathus mormyrus</i> (sandsteenbras)	"	"	"	"	"	"	"
0.36 (0.31-0.42)	<i>Diplodus sargus</i> (blacktail)	"	"	"	"	"	"	"

Table 5. (continued)

un-ionized ammonia-N concentration (mg l ⁻¹)	species	stage in life history exposed	salinity	temp. (°C)	pH	response	source of ammonia	reference
		C. Freshwater and marine fish: feeding and growth effects						
0,72 (0,53-1,00) ³	<u>Ictalurus punctatus</u>	juvenile	fresh water	22,1-22,8	7,7-8,0	stopped eating when ammonia reached this level ⁴	excreted by fish	Knepp & Arkin, 1973
0,75	<u>Microstomus pacificus</u> (Dover sole)	"	sea water	(not given)	(not given)	just sufficient to completely stop feeding	(not given)	Alderson (1976 pers. comm. cited by Hampson, 1976)
0,41	"	"	"	"	"	87% decrease in growth rate	"	"
0,13 (0,11-0,14)	<u>Ictalurus punctatus</u>	juvenile	fresh water	25-26	7,8	significant reduction in growth rate (relative to control) during month-long exposure	NH ₄ OH	Robinette, 1976
0,06 (0,05-0,07)	"	"	"	25,3	7,6	growth not significantly different from that of control during month-long exposure	"	"
0,22 (0,17-0,28)	<u>Pachymetopon blochii</u>	first-feeding larva	sea water	15	7,8-7,9	24-h first-feeding EC50	NH ₄ Cl	(this study)
0,16 (0,11-0,23)	Species 5 (unidentified)	"	"	"	"	"	"	"
0,16 (0,11-0,22)	<u>Lithognathus xanthurus</u>	"	"	"	"	"	"	"
0,11 (0,09-0,13)	<u>Gaidropsarus capensis</u>	"	"	"	"	"	"	"
0,10 (0,06-0,15)	<u>Diplodus sargus</u>	"	"	"	"	"	"	"

footnotes: 3. The value 0,53 is based on 32 mg l⁻¹ total ammonia (as NH₄⁺) at 21,1°C and pH 7,7; 1,00 is based on 27,6 mg l⁻¹ at 22,8°C and pH 8,0; 0,72 is the geometric mean of these two extremes.

4. Collins et al. (1975) argued that nitrite, and not un-ionized ammonia, was responsible for the responses described by Knepp and Arkin (1973).

& Elmaraghy, 1977).

The response of marine fish to ammonia is very poorly known. Hampson (1976, pers. comm. from Alderson) published data on the tolerance of two marine pleuronectids to un-ionized ammonia. They are clearly more tolerant than salmonids tested in fresh water, but may not be more tolerant than certain non-salmonids (e.g. Ictalurus (Colt & Tchobanoglous, 1976)). Increasing the salinity of the dilution water seems to increase the tolerance of some freshwater fish (those that are not placed under stress by the salinity change, itself) to un-ionized ammonia. Rainbow trout yielded a 24-h LC50 at 10‰S (approximately isotonic with its blood) of twice that at 0‰S and 36‰S (Herbert & Shurben, 1965). At 15°C, stickleback (Gasterosteus aculeatus) yielded 96-h LC50's of 0,42, 1,46, and 3,71 mg l⁻¹ NH₃-N (un-ionized) at salinities of 0, 11, and 33‰S, respectively (Hazel et al., 1971: these authors' mean values were recalculated using pK_a values from Emerson et al. (1975) with Whitfield's (1974) salinity correction). At 23°C the tolerance was slightly greater, but still salinity-dependent: 0,65, 1,21, 1,48 mg l⁻¹, respectively. Juvenile striped bass (Morone saxatilis) behaved more like Herbert & Shurben's trout, with maximal tolerance at intermediate salinity: at 15°C, 96-h LC50's were 0,56, 0,79, and 0,71 mg l⁻¹ at salinities of 0, 11, and 33‰S, respectively; at 23°C, 0,68, 1,06, and 0,97 mg l⁻¹, respectively.

Based simply on inspection of the response curves presented here, one might predict the maximum concentration of un-ionized ammonia that negligibly affects first-feeding following a 24-h exposure to lie between 0,02 and 0,05 mg l⁻¹ NH₃-N (un-ionized). At 15°C, 35‰S, and pH 7,85, this would correspond to a total ammonia concentration of 1,4 to 3,4 mg l⁻¹ N.

4.3 NO_2^-

4.3.1 Specific methods

Treatment solutions were prepared by mixing quantities of a concentrated stock solution of NaNO_2 (4,70 M), measured by micropipette, with system water. No dose-uncertainty adjustments were made to confidence limits of the curves. A log/normal distribution of tolerance was assumed.

4.2.2 Results and discussion

Five species were tested (fig. 12): the gadid, Gaidropsarus capensis; the two soleids, Heteromycteris capensis and Synaptura kleini; and the two sparids, Lithognathus mormyrus and Diplodus sargus. The 24-h first-feeding EC_{50} for G. capensis was 450 (380-530) $\text{mg l}^{-1} \text{NO}_2\text{-N}$, the other four species yielded EC_{50} 's between 330 and 360 mg l^{-1} , with 95% confidence limits ranging from 240 to 500 mg l^{-1} . EC_{10} 's ranged from 63 to 280 mg l^{-1} . 24-h LC_{50} values for the gadid and two soleids were between 2110 and 2440 mg l^{-1} ; those for the two sparids were between 1360 and 1230 mg l^{-1} .

The contrast between these figures and those of salmonids tested in fresh water of low dissolved solids (e.g. a 96-h LC_{50} of 0,23 $\text{mg l}^{-1} \text{NO}_2\text{-N}$ (Brown & McLeay, 1975: Salmo) and 0,88 mg l^{-1} (Westin, 1974: Oncorhynchus)) is astounding. Even the chinook salmon (O. tshawytscha) tested by Crawford & Allen (1977) in sea water exhibited less tolerance than the above larvae: those authors reported a 10% mortality after 48-h exposure to 326 $\text{mg l}^{-1} \text{NO}_2\text{-N}$.

A few authors have reported nitrite concentrations in tanks where marine fish were being reared. Riley and Thacker (1963, fig. 5) showed nitrite concentration peaking at about 0,05 mg l^{-1} (=3,7 $\mu\text{g-at l}^{-1}$) $\text{NO}_2\text{-N}$ towards the end of a plaice-rearing experiment. This value falls just

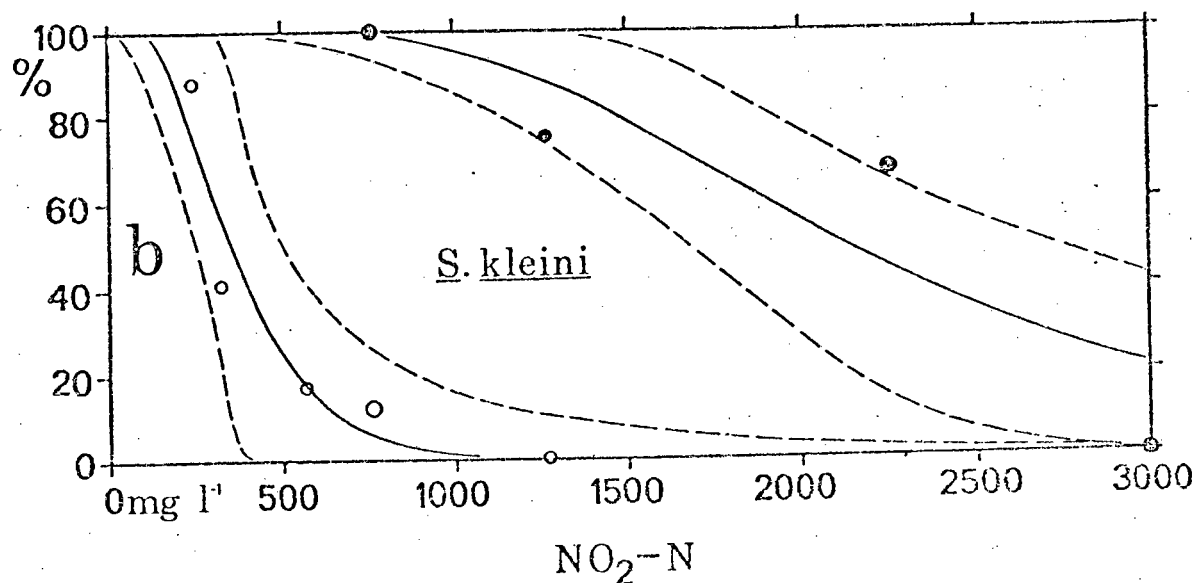
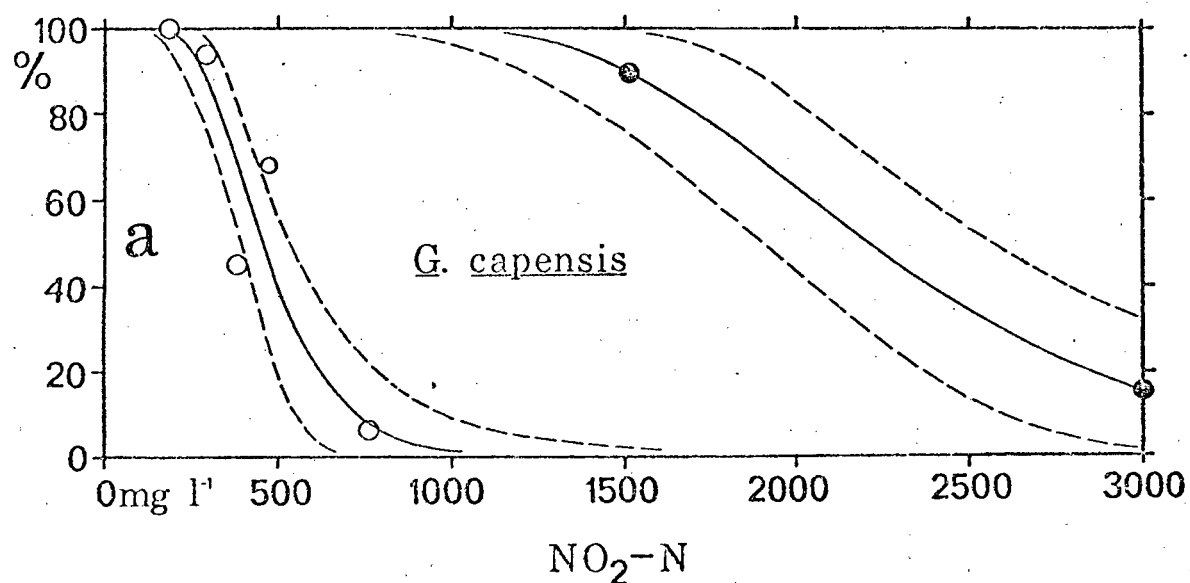


Figure 12. Response of first-feeding (a) *Gaidropsarus capensis*, (b) *Synaptura kleini*, (c) *Heteromycteris capensis*, (d) *Lithognathus mormyrus*, and (e) *Diplodus sargus* to nitrite. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various nitrite concentrations. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding nitrite concentrations. The solid curves were fitted by assuming a log/normal distribution of tolerance. 95% confidence limits are represented by dashed lines.

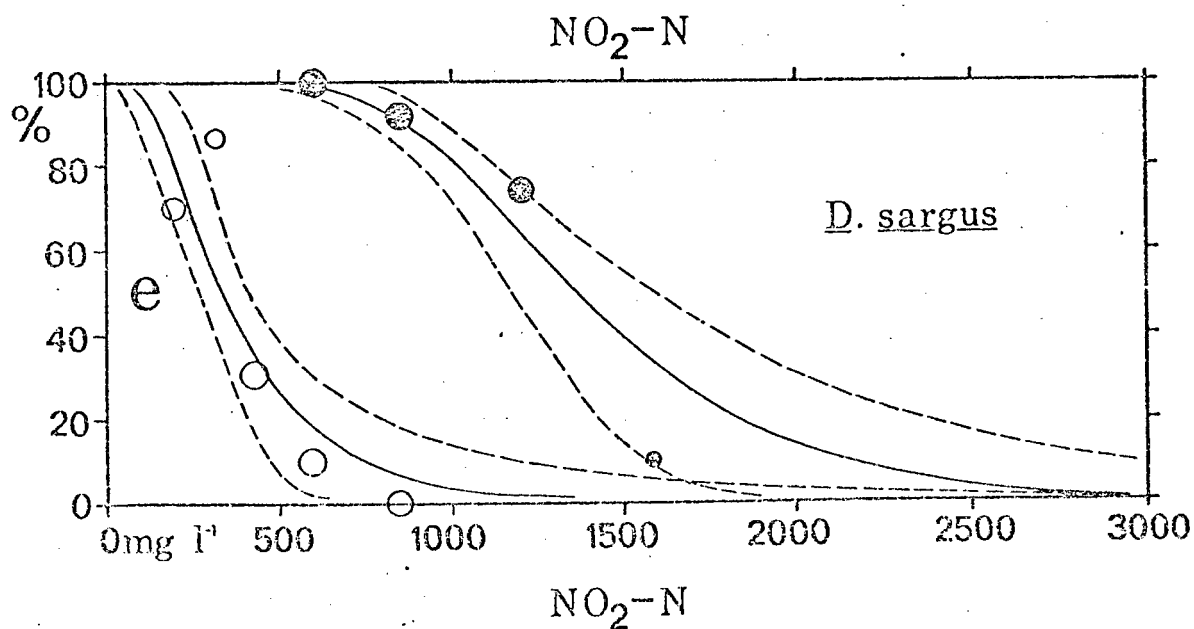
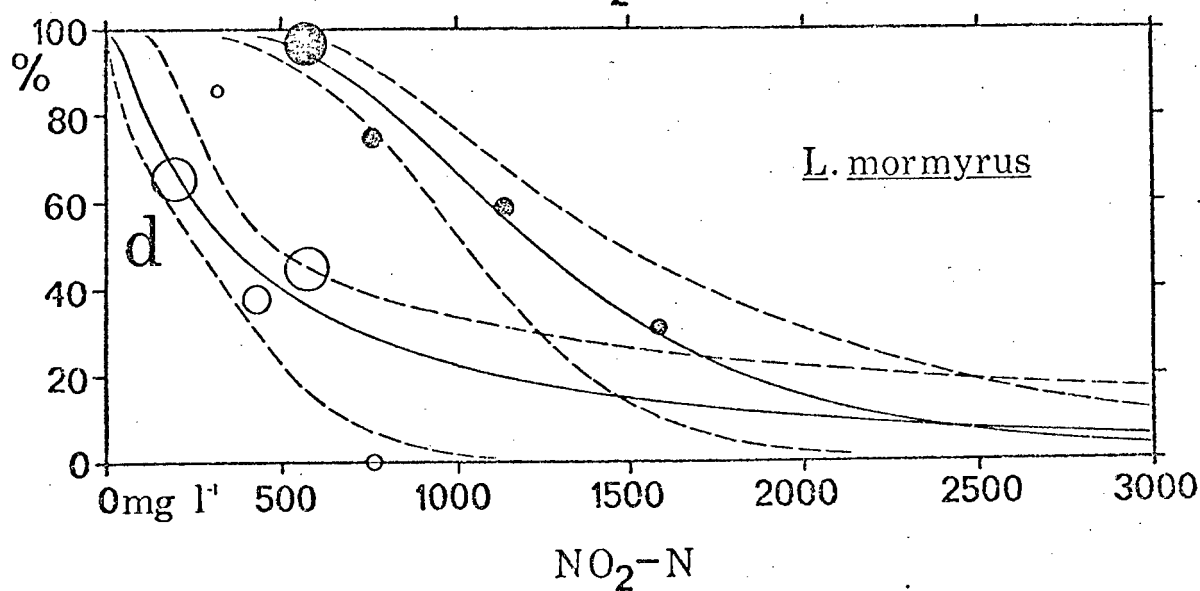
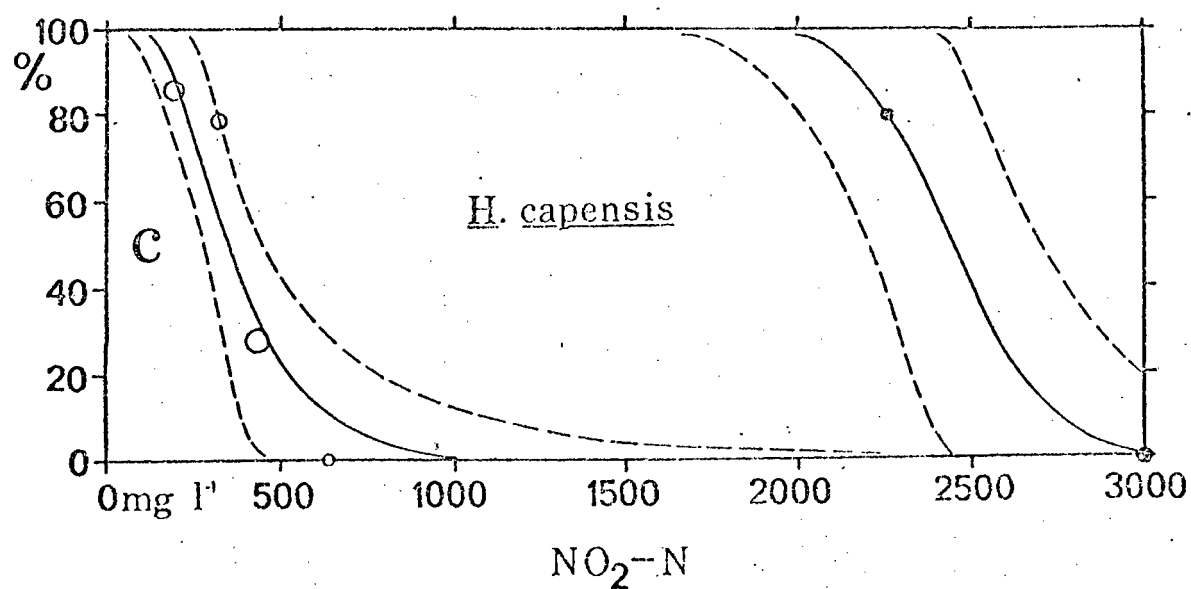


Figure 12. (continued)

within the range (0,01-4 $\mu\text{g-at l}^{-1}$ $\text{NO}_2\text{-N}$) found in oceanic surface waters (Kinne, 1976:93). Barnabé (1976b, Table II) recorded nitrite levels in a tank where larval seabass, Dicentrarchus labrax, were being reared. The values fell between 0,005 and 0,023 mg l^{-1} $\text{NO}_2\text{-N}$. In an experiment where 5 g of mussel flesh was allowed to decompose in each of two 8-l tanks of sea water, one aerated, the other static (Kühl & Mann, 1956), nitrite concentration eventually peaked at 15,2 and 12,2 mg l^{-1} $\text{NO}_2\text{-N}$, after about 35 and 60 days, in the aerated and static tanks, respectively. It appears highly unlikely that nitrite levels of this magnitude would be produced in a rearing tank if any attention, whatsoever, is paid to hygiene and water quality. One must conclude that however varied and great the problems of the marine-fish nurseryman may be, nitrite poisoning is not likely to be one of them. It is interesting that, although marine prawns (Penaeus indicus) tolerated 3-4 times as much nitrite as freshwater prawns (Macrobrachium rosenbergi), the asymptotic LC_{50} was still only in the range 30-60 mg l^{-1} $\text{NO}_2\text{-N}$ (Wickins, 1976, fig. 4).

4.4 NO_3^-

4.4.1 Specific methods

Treatment solutions were prepared by mixing quantities of a concentrated stock solution of NaNO_3 (4,60 M), measured by micropipette, with system water. No dose-uncertainty adjustments were made to confidence limits of the curves. A log/normal distribution of tolerance was assumed.

4.4.2 Results and discussion

First-feeding larvae of four species were exposed to various nitrate concentrations (fig. 13): the gadid, Gaidropsarus capensis; the soleid, Heteromycteris capensis; and the two sparids, Diplodus sargus and Lithognathus mormyrus. All four species proved to be tolerant of very

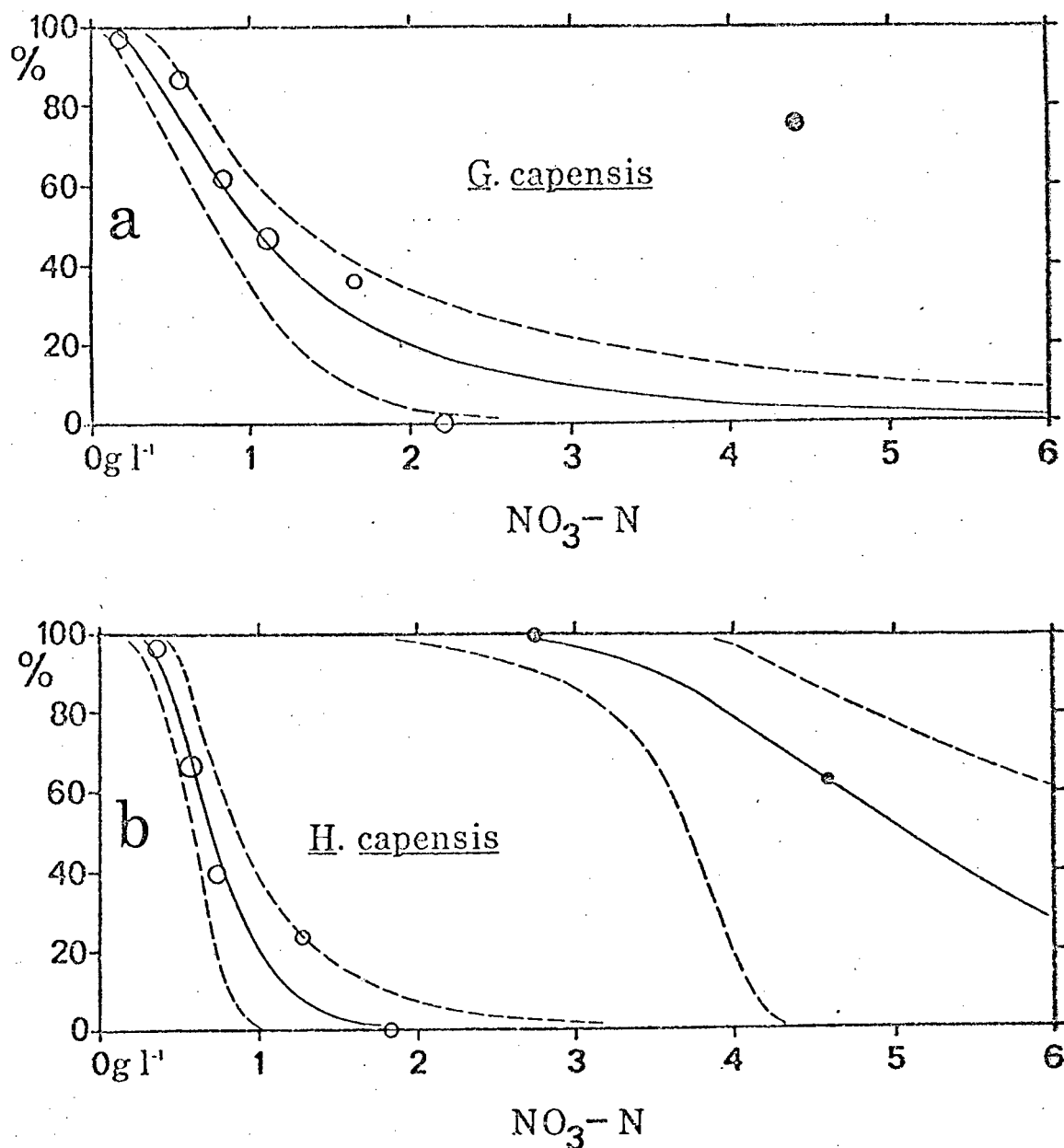


Figure 13. Response of first-feeding (a) *Gaidropsarus capensis*, (b) *Heteromycteris capensis*, (c) *Diplodus sargus*, and (d) *Lithognathus mormyrus* to nitrate. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various nitrate concentrations. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding nitrate concentrations. The solid curves were fitted by assuming a log/normal distribution of tolerance. 95% confidence limits are represented by dashed lines.

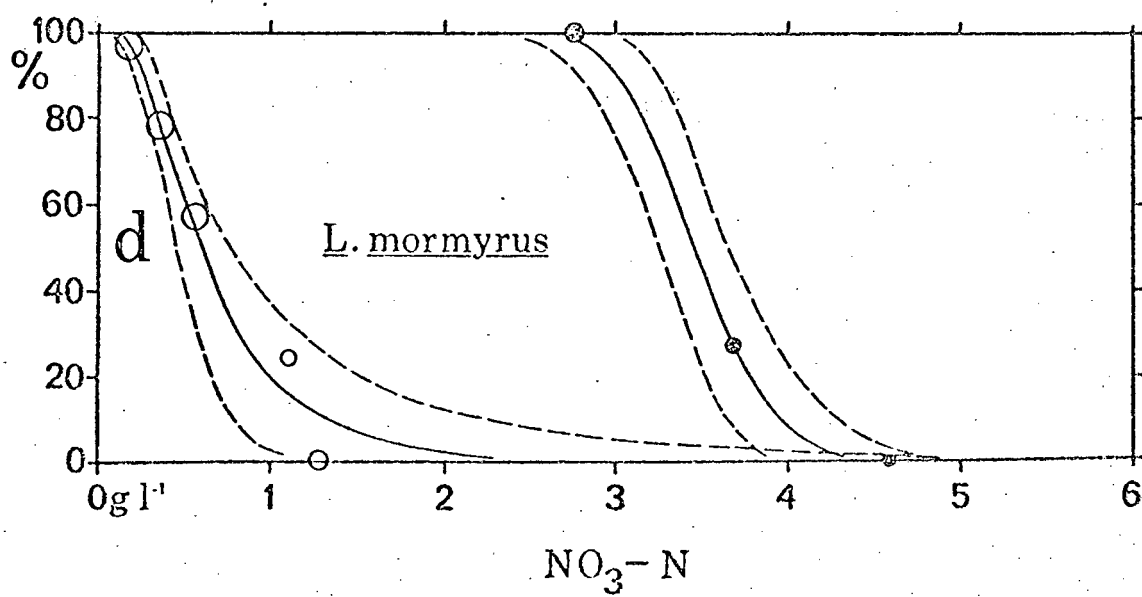
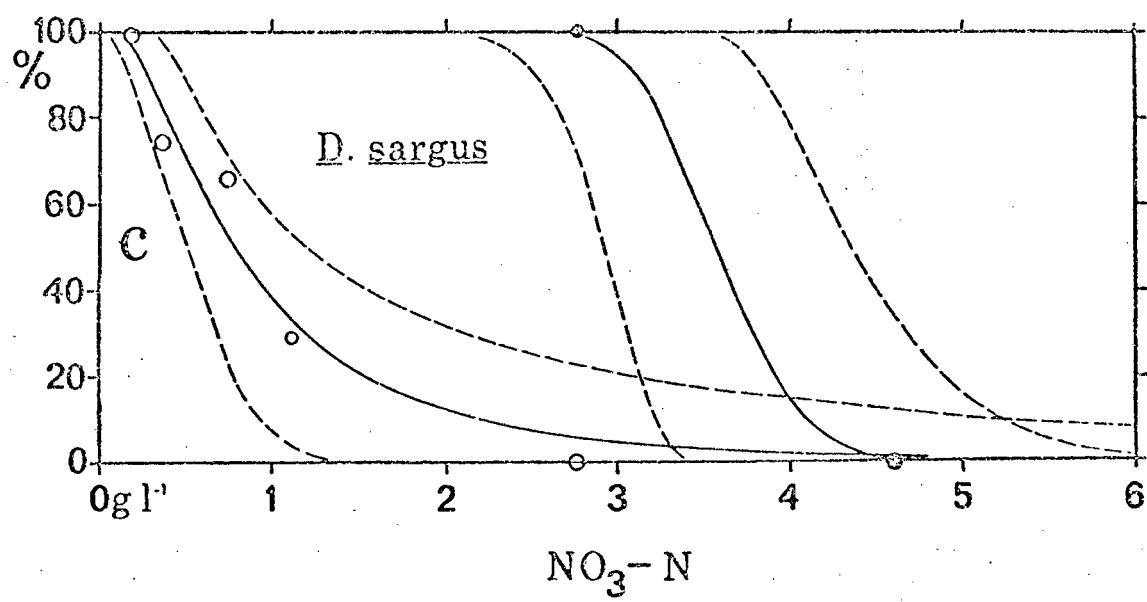


Figure 13. (continued)

high nitrate levels, the 24-h first-feeding EC50's being 1020 (770-1520), 710 (590-869), 780 (510-1200), and 600 (470-760) mg l⁻¹ NO₃-N, respectively. 24-h LC50's fell between 4,2 and 8,7 g l⁻¹.

A comparison of these figures with those from the literature reveals that these marine larvae are considerably more tolerant of elevated nitrate than any of the juvenile and adult freshwater fish studied thus far. Freshwater fish have yielded LC50's in the range 1-2 g l⁻¹ NO₃-N, e.g. rainbow trout (Salmo gairdneri), 96-h LC50 of 1350 mg l⁻¹ (Westin, 1974); mosquitofish (Gambusia affinis), 24-h LC50 of 1940 mg l⁻¹ (Wallen et al., 1957); channel catfish (Ictalurus punctatus), asymptotic LC50 of 1420 mg l⁻¹ (Colt & Tchobanoglous, 1976); bluegill (Lepomis macrochirus), 96-h LC50 of 1970 mg l⁻¹ (Trama, 1954). All the above-mentioned studies used NaNO₃ as the source of nitrate. Ca(NO₃)₂ (Trama, 1954) and KNO₃ (Trama, 1954, Rubin & Elmara-ghy, 1977) are more toxic. Sublethal effects of nitrate reportedly occur at much lower concentrations. Braun (1972, cited by Bohl, 1977) found a complete cessation of feeding by rainbow trout at 180 mg l⁻¹ NO₃-N.

With the possible exception of the last-mentioned, none of the above nitrate concentrations are likely to develop naturally in a closed culture system. According to Saeki (1958, reviewed by Kinne, 1976:170), nitrate in the Ueno Aquarium (sea water) was reduced (by bacterial denitrification) as fast as it was produced, once the concentration reached about 100 mg l⁻¹ NO₃-N. However, Honig (1934) found 160 mg l⁻¹ in the Aquarium of the Koninklyk Zoölogisch Genootschap Natura Artis Magistra in Amsterdam, and Oliver (1957) reported 310 mg l⁻¹ NO₃-N in the recirculating water of the Aquarium of the Zoological Society of London. These accumulations of nitrate occurred over many years of water re-use.

The cause of mortality in freshwater fish in nitrate toxicity tests is probably related, as Colt & Tchobanoglous (1976:219) suggested, "to the failure of the fish to maintain proper osmoregulation when transferred to water containing a high salt content." When converted to ‰ total dissolved solids, the 96-h LC50 for bluegill in NaNO_3 solutions was 12,0‰S; in NaCl solutions, the 96-h LC50 was only slightly greater: 12,9‰S (Trama, 1954). Because of the high concentration of the stock solution used in the present study (4,60 M), the resulting salinity of the test water exceeded that of the controls. The salinity at 24-h first-feeding EC50 levels ranged from 39 to 41‰S (730 mg l^{-1} to 1160 mg l^{-1}); 24-h LC50 salinities ranged from 59 to 83 ‰S (4,2 g l^{-1} to 8,7 g l^{-1}). Salinity of controls was 35‰S. In a single experiment designed to compare the response of larvae to chloride-enhanced salinities equivalent to the nitrate-enhanced salinities presented above, the author tested first-feeding and survival in the sole, Heteromyceteris capensis, following 24-h exposure to NaCl -enriched seawater solutions of 40, 50, and 70‰S, in addition to the control of 35‰S. The larvae allocated to the four test containers came from the same batch and were tested simultaneously. They were pipetted directly from system water into the prepared solutions without gradual acclimation (i.e. using the same methods followed in the nitrate experiments). First-feeding incidence at 40‰S was 96% (14 fed out of 18) that of the control (17 fed out of 21), suggesting negligible impairment of first-feeding at this salinity. At 50‰S, feeding incidence was 59% (13 fed out of 27) that of the control, which is shown by a Chi-square test to be significantly ($p < .05$) less. These data argue that the feeding inhibition observed in nitrate solutions below a concentration of about 1000 mg l^{-1} (equivalent to a salinity of 40,5‰S) cannot simply be attributed to the osmolarity of

the test water. The fact that there was 15% mortality at 50‰S (none in the control), and 100% (n=20) at 70‰S, however, implies that the lethal toxicity of nitrate, in the present study, can just as easily be attributed to elevated salinity.

4.5 H⁺

4.5.1 Specific methods

Quantities of a concentrated (about 4 N) HCl stock solution were micropipetted into test containers holding system water, and the mixture was vigorously aerated for an hour before measuring pH (NBS). Sixty minutes of aeration was found to be sufficient to reduce free CO₂ concentration to within 10% of equilibrium levels. If the resulting pH was not satisfactory, additional HCl or additional system water was added and aeration resumed for another 30 minutes. The larvae were first transferred from the larva baskets into system water which had been acidified to about pH 3, aerated, and brought to neutrality by addition of NaOH. From there, the larvae were pipetted into the test solutions. Food was resuspended in a small quantity of the decarbonated water prior to addition. A second pH reading was taken at the end, after fish had been rated and removed. The nominal pH was the arithmetic mean of the initial and final pH's recorded. Uncertainty as to the actual pH during exposure was greatest near the pH inflexion point (about pH 4,5). A value of 0,42 - 0,06 pH_m (where pH_m is the predicted mean effective pH at any response percentile) was added to, or subtracted from, the upper and lower 95% confidence limits, respectively, to account in some way for pH uncertainties. A normal distribution of tolerance over units of pH was assumed in fitting response curves.

4.5.2 Results and discussion

Three species were tested (fig. 14): the gadid, Gaidropsarus capensis; the soleid, Heteromycteris capensis; and

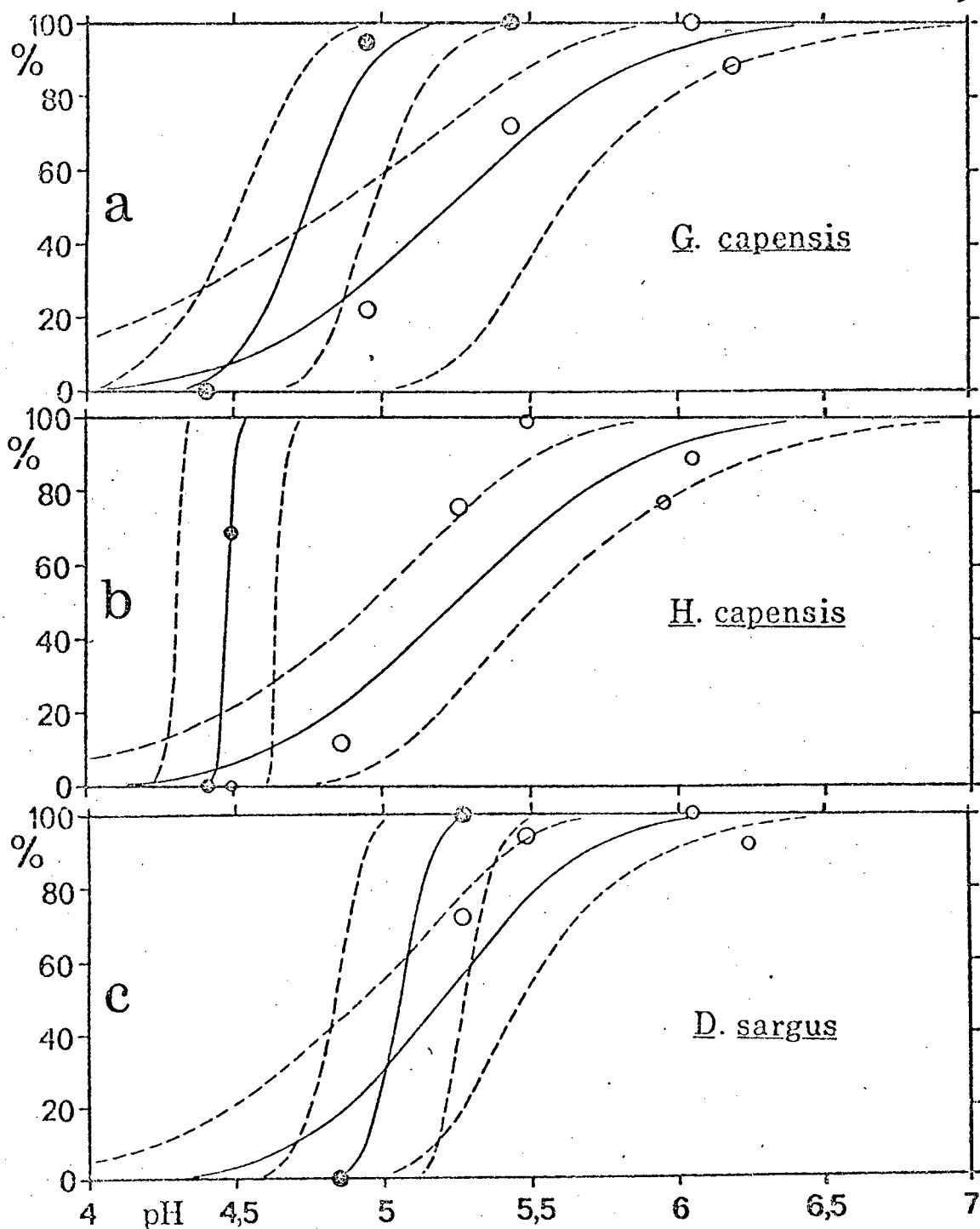


Figure 14. Response of first-feeding (a) *Gaidropsarus capensis*, (b) *Heteromycteris capensis*, and (c) *Diplodus sargus* to low pH. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various low pH's. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding pH's. The solid curves were fitted by assuming a normal distribution of tolerance over un-transformed units of pH. 95% confidence limits are represented by dashed lines.

the sparid, Diplodus sargus. For all three, the 24-h first-feeding EC50 fell between pH 5,2 and 5,3 (95% confidence limits ranging as high as pH 5,6), and the EC10's fell between pH 5,7 and 5,9 (95% confidence limits ranging as high as pH 6,3). The 24-h LC50's were between pH 4,5 and 5,1 (95% confidence limits ranging from pH 4,3 to 5,3.) The tolerance of these larvae to low pH came as a surprise. The data argues credibly that marine fish are practically as tolerant to low pH as their freshwater cousins, at least in the short term.

The reduction of free CO₂ in these experiments to very near atmospheric equilibrium removes this factor from consideration, and makes direct comparison with results of some of the freshwater studies possible. Trojnar (1977a) exposed newly-fertilized white sucker (Catostomus commersoni) eggs to various H₂SO₄ concentrations, and recorded percent hatch and percent survival to swim-up stage. Free CO₂ had been reduced to equilibrium levels by aeration. At pH 5,8 there was no significant reduction in survival to swim-up; at pH 5,3 there was a significant reduction; at pH 5,0 none of the larvae survived to swim-up. In a study on brook trout (Salvelinus fontinalis) eggs and larvae (Trojnar, 1977b), hatchability was 76% at pH 4,6, as compared to 91% at pH 8,1 (control). 96,5% of the larvae incubated at pH 4,6 were still alive after 14 days continued exposure to the same pH. Milbrink & Johansson (1975) and Johansson & Milbrink (1976) compared pH tolerance of roach (Rutilus rutilus) and perch (Perca fluviatilis) eggs in both laboratory and field studies. Dilution water in the laboratory experiments was allowed at least three days to equilibrate after addition of HCl. On the basis of exposures lasting throughout the embryonic phase and using hatching success as the criterion, they derived a tolerance limit for roach of about pH 5,5, and for perch, about 4,7. Pike (Esox lucius) egg tolerance, determined similarly, was about

pH 5,0. Pike yolk-sac larvae yielded slightly reduced survival as a result of 8 days exposure to pH 5,2 (percent survival was 89% that of control) (Johansson & Kihlström, 1975). The range of pH's coming out of the above-mentioned freshwater egg and larva studies (where free CO₂ has been reduced to equilibrium levels) is about pH 4,5 to 5,5—very comparable to the range of pH's derived in the present study using marine fish larvae. Studies where free CO₂ concentration may have been large enough to affect the results (e.g. Mount, 1973: Pimephales; Davies, 1973: Morone; Menendez, 1976: Salvelinus) yielded higher pH's as limiting values. (An exception seems to be flagfish (Jordaniella floridae) larvae, where growth and survival were impaired at pH 6 (Craig & Baksı, 1977), although, based on the alkalinity of the dilution water, free CO₂ could not have exceeded about 1,3 mg l⁻¹ CO₂-C in any of the treatment pH's. This is below the level of CO₂ that would be expected to influence pH limits). No published information on the tolerance of marine fish eggs or larvae to low pH was encountered where a satisfactory distinction was made between toxicity due to hydrogen ion and that due to carbon dioxide.

From the results of the present study, it might be asserted that the maintenance of pH and carbonate alkalinity in closed and semi-closed fish culture systems at levels approximating those in the sea is unnecessary. Hirayama (1970) monitored pH and alkalinity (as well as ammonia and nitrate) in a small closed marine system in which juvenile sparids (Acanthopagrus) were kept. Alkalinity decreased linearly with time to a value of 0,2 meq l⁻¹ and pH below 6,0 with the fish showing no abnormal symptoms. Although a pH-related inhibition of nitrification has been reported (Saeki, 1958; Kawai et al., 1965), the nitrifying capacity of Hirayama's filter was still adequate to keep ammonia at a low level, and even at pH 4,8, and nearly 0 meq l⁻¹ alkalinity, nitrification did not cease completely.

The reward of operating a recirculating culture system at a lower pH would be the reduction in $\text{NH}_3:\text{NH}_4^+$ ratio. Before any such recommendation can be made, however, it will first be necessary to weigh the gain in ammonia ratio against possible long-term pH effects on fish larvae, bacteria, and ionic balance of the recirculating water.

4.6 OH^-

4.6.1 Specific methods

Varying amounts of a strong (about 4 N) stock solution of NaOH in distilled water were added to system water in 350-ml test containers to yield an array of treatment concentrations. The solutions were then aerated for an hour, pH (NBS) was measured, and larvae were added. The pH of the water was again measured after the larvae had been removed. Change in pH during the 28-h experiments were caused by addition of system water along with the fish and food—10 ml and 5 ml, respectively. The nominal pH was the mean of the initial and final pH's recorded. The 95% confidence limits of computed response curves were expanded by a value that took into consideration the instrument error in measuring pH and the variation in pH during tests, ie, $0,0142 \text{ pH}_m - 0,077$. A model assuming a normal distribution of tolerance over units of pH was employed in the fitting of the response curve.

4.6.2 Results and discussion

Figure 15 demonstrates a uniformity in first-feeding tolerance among the three species tested—the gadid, Gaidropsarus capensis; soleid, Heteromycteris capensis; and sparid, Diplodus sargus: a 50% reduction in first-feeding incidence occurred at approximately pH 8,7, 8,8, and 8,8, respectively. A 10% reduction occurred at approximately pH 8,4, 8,5, and 8,5, respectively. 24-h LC50's obtained

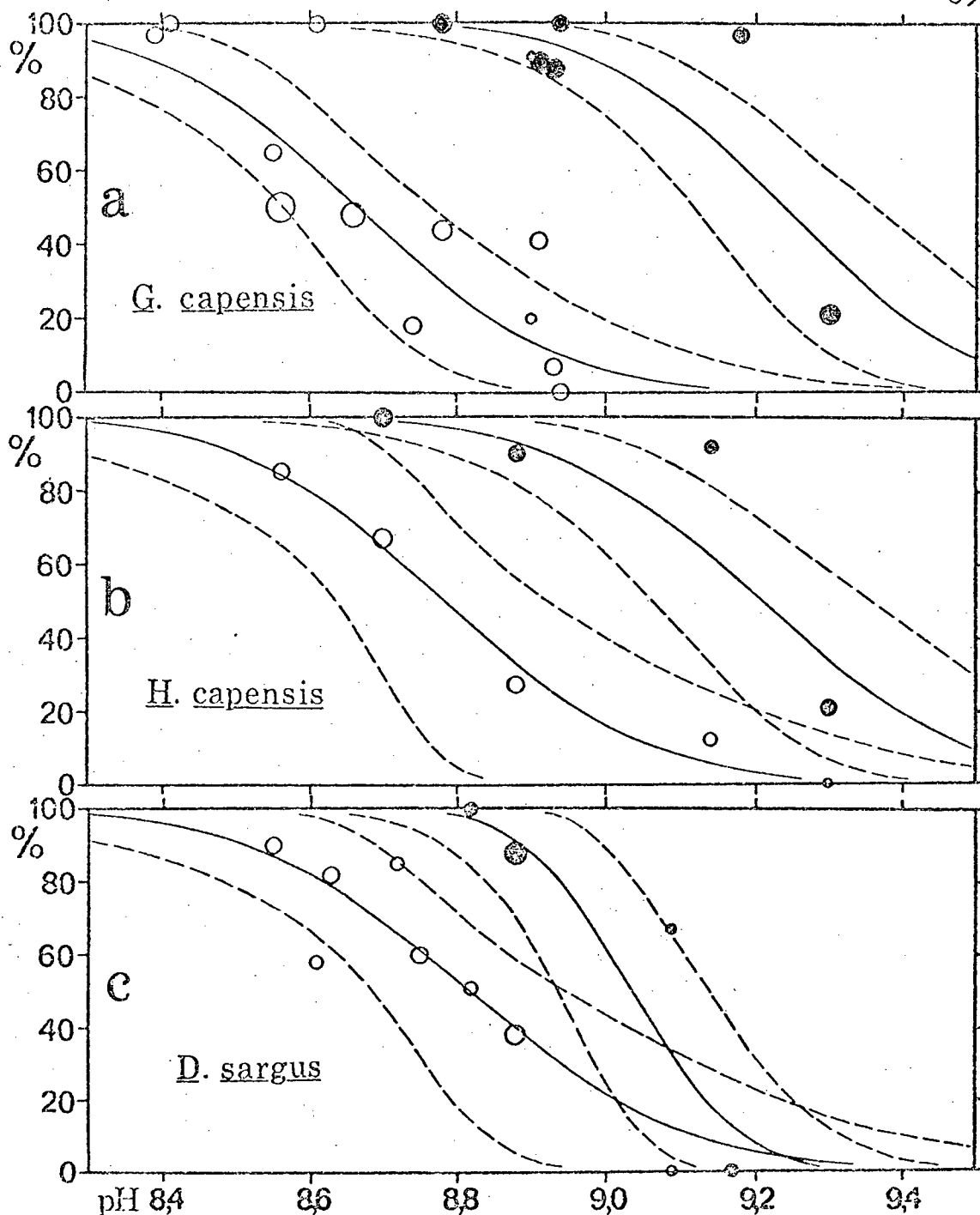


Figure 15. Response of first-feeding (a) *Gaidropsarus capensis*, (b) *Heteromyceteris capensis*, and (c) *Diplodus sargus* to high pH. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various high pH's. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding pH's. The solid curves were fitted by assuming a normal distribution of tolerance over un-transformed units of pH. 95% confidence limits are represented by dashed lines.

for the three species were approximately 9,2, 9,2, and 9,0, respectively. Based on these data, a negligible-effect pH is not likely to exceed pH 8,4. This value is only marginally higher than the more extreme pH's recorded in the open sea: pH 8,3 (Sverdrup et al., 1942), and in light of the trend toward rearing marine fish larvae in green water, might pose a serious limit for the nurseryman.

Comparisons of these values with those of previous workers is difficult, chiefly because of the variation in experimental conditions. Schach (1939) reported the limits of tolerance for Atlantic herring larvae (Clupea harengus harengus) as pH 8,45, and the optimal range as 8,2-8,3. Bishai's (1960) larvae (same species) died when the pH was raised from 8,1 to 8,5, reportedly by addition of NaHCO_3 . Kelley (1946) found that Pacific herring (C. h. pallasii) eggs hatched a day sooner when they were incubated at pH 8,68 (range during exposure: 7,93-8,96), but that percent survival through hatching was not different from controls. A marked decrease in hatchability occurred in another experiment when pH rose to 9,12. No other data on the tolerance of the early stages of marine fish appear to be available.

Eggs and larvae of freshwater fish seem to tolerate somewhat higher pH's than those derived here for marine fish larvae, but this needs to be confirmed on the basis of appropriate sublethal responses. Bishai (1960) tested larvae of three salmonid species: all three (Salmo salar, S. trutta, S. gairdneri) apparently survived 40 days at pH 9 and 60% of the S. salar larvae survived 15 days at pH 10. Krishna (1953) reported low mortalities among eyed eggs and larvae of trout (species and exposure duration not recorded, but the latter clearly exceeded 6 h) at pH 9, and high mortalities at pH 9-10. Bonn (1970, cited by Humphries & Cumming, 1973) derived a "lethal limit" for larval striped bass (Morone

saxatilis) of pH 10.

A certain amount of acclimation to elevated pH has been demonstrated by Jordan & Lloyd (1964). These authors found that juvenile rainbow trout held in water of pH 8,4 for five days tolerated further increases in pH significantly better than individuals held in water of pH 6,55 and 7,50 for the same period. The improved growth rate of juvenile sole (Solea solea) over a 13-day period in tanks where the pH averaged about 8,4 and rose eventually as high as 8,8 (due to phytoplankton production) (Alderson & Howell, 1973) suggests either that acclimation to elevated pH occurs, or that juvenile marine fish are simply more tolerant than larvae. It may be that the marine larvae in the present study, given a more gradual exposure increase, would have better tolerated high pH's. Further research on the response of fish larvae, both freshwater and marine, to elevated pH (particularly that associated with phytoplankton blooms) is sorely needed.

4.7 O₂

4.7.1 Specific methods

The tolerance of first-feeding larvae to low dissolved oxygen concentration was investigated by both static and flow-through techniques.

Static tests

System water, de-oxygenated to varying degrees by nitrogen stripping, was placed in 350-ml test containers. Oxygen concentration was measured with a YSI-57 O₂ meter and probe. Larvae were introduced by pipette (along with 10 ml of system water) and the container was closed with a screened bung into which a small wad of synthetic wool had been pressed. After 24 h, the wool plug was removed, food was added (along with 3 ml of system water), and the plug was replaced in the bung. O₂ was again measured immediately

after the larvae had been rated and removed.

Increases in the O_2 concentration during the course of the experiments came as a result of diffusion of atmospheric oxygen through the wool plug, by addition of O_2 with larvae and food, and during removal of larvae; decreases resulted from respiration by bacteria, food, and fish. A relationship between the O_2 concentration measured at the beginning (O_2 init) and at the end (O_2 final) to the average concentration to which larvae were actually exposed was derived empirically by fitting lines to measurements made during dummy runs. The nominal values were calculated according to the expression:

$$O_2 \text{ nom} = 0,42 O_2 \text{ init} + 0,52 O_2 \text{ final} + 0,42$$

Upper and lower 95% confidence limits of the calculated response curves were expanded by addition and subtraction, respectively, of the value: $0,036 O_{2m} + 0,27$. (where O_{2m} is the predicted mean effective concentration at any response percentile). The adjustment accounts, in an approximate way, for instrument error and variation in O_2 during exposures.

Flow-through tests

The flow-through apparatus (fig. 16, table 6) accomodates one control and four treatments. Briefly, water from the closed circulation system is de-oxygenated to varying degrees in a nitrogen stripping column, passed through the test containers holding the larvae, re-oxygenated, and returned to the system. Fry (1951) must be given credit as the developer of this kind of de-oxygenation device for use in tolerance testing of aquatic animals.

Uniformity in O_2 concentrations delivered to test containers during the course of an experiment required close control over both water and nitrogen flow rates. This gravity-feed system, similar in principle to that described by Granmo & Kollberg (1972), was found to be

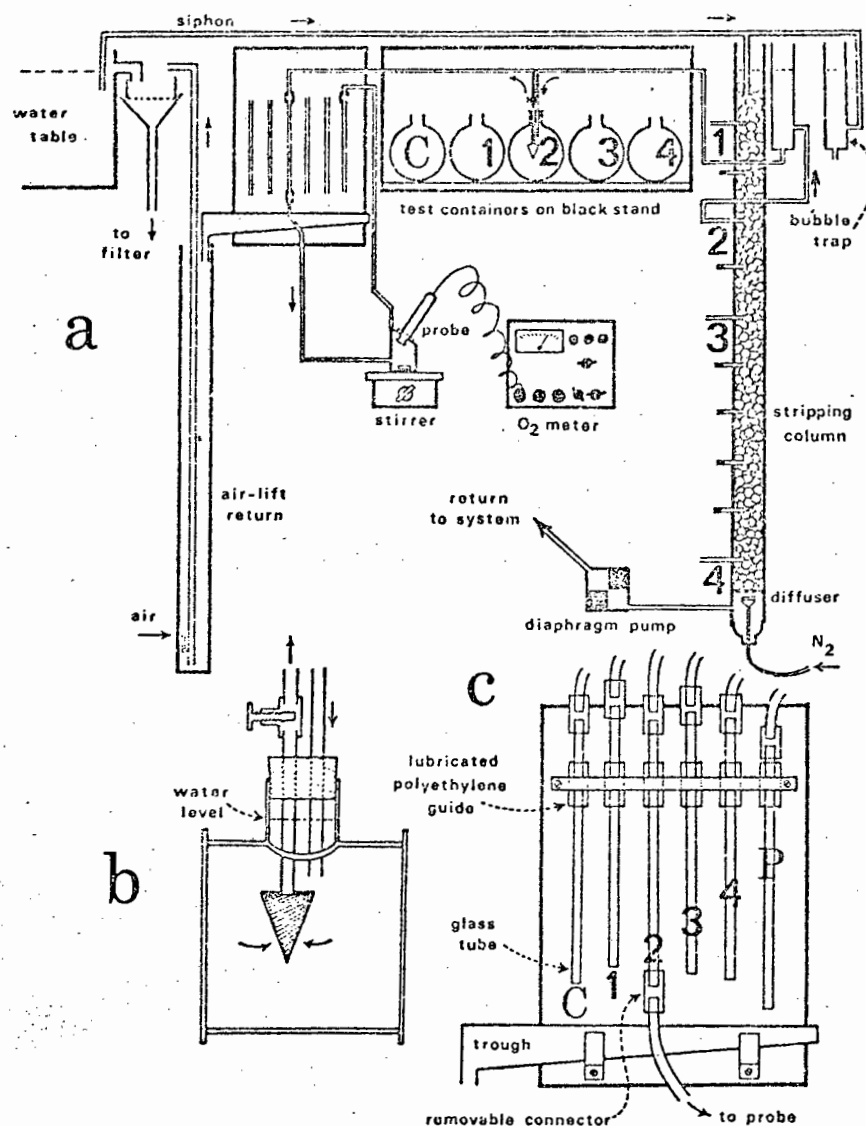


Figure 16. The flow-through apparatus used for testing the tolerance of first-feeding larvae to low dissolved oxygen. (a) General view, not to scale. Only one channel (treatment no. 2) is shown, with probe circuit attached. Two of the five bubble traps are shown. (b) Side view of test container with conical 40 μ m mesh and valve on outlet. (c) Flow-control device.

very reliable. The procedure used was as follows: 1) Larvae were apportioned among five 350-ml test containers filled with system water (O_2 very near saturation). 2) The column was filled with water, nitrogen introduced at a constant rate, and the test containers connected. 3) The tube leading to the oxygen probe was fitted to one of the glass tubes of the treatment channels. 4) With the valves on the

Table 6. Some physical characteristics of the flow-through de-oxygenation apparatus.

stripping column	clear perspex
depth of water in column	1 m
volume of water in column	900 ml
inside diameter	44 mm
packing	1,5 cm $\varnothing$ glass marbles
flow rate of water entering column	230 ml min ⁻¹
flow rate of nitrogen entering column	20-100 ml (STP) min ⁻¹
tubing	4 mm ID polyethylene
bubble traps	36 mm ID rigid PVC with perspex bottom
volume	150 ml
test containers	350 ml, glass and perspex with silicone sealant seams
bung	rubber (does not come in contact with water)
netting	nylon, 40 μ m mesh openings
flow rate through each container	20 $\pm$ 2 ml min ⁻¹
time to exchange 90% of water	40 $\pm$ 3 min

container out-flow lines in fully open position, a slight suction on the end of each of the glass tubes of the flow-control device initiated the flow. The valves were then closed down until a head of roughly 25 cm (measured from the water-line of the water table to the bottom of the glass tubes) would produce a flow rate of about 20 ml min⁻¹ through each container. 5) By independently raising or lowering the glass tubes (thereby altering the head), the rate of dripping was synchronized with the ticking of a noisy alarm clock, which happened to yield a flow rate of almost exactly 20 ml min⁻¹ from each glass tube. 6) Approximately one hour was required to bring the oxygen concentration from 8,1 mg l⁻¹ (system water) to the desired levels; the nominal 24-h exposure began one hour after connecting the test containers. 7) At the end of 24 h, a count of survivors was made visually, without disconnecting the containers. 8) A concentrated suspension

of rotifers was equally distributed among the five bubble traps. 9) After 4 h, one container at a time was disconnected, replaced by a container full of system water only, and then examined in the usual manner with the suspended microscope. In this way, the oxygen levels in the remaining containers were not affected by a decrease in the flow-rate of water through the column while the feeding incidence was being determined.

It was found that variation in flow rate due to bubble formation in the tubing was not a problem as long as the head was greater than about 20 cm. For additional assurance, a 150-ml min⁻¹ diaphragm pump (fig.16) was used to dampen the effect of any variation in flow through one or more of the treatment channels.

Confidence limits of computed response curves were expanded by addition or subtraction of a value: $0,041 O_{2m} + 0,24$ (where O_{2m} is the predicted mean effective concentration at any response percentile) to account for instrument error and variation in O_2 concentration during tests. For both static and flow-through data, response rate was linearized by assuming a normal distribution of tolerance over un-transformed units of DO concentration.

4.7.2 Results and discussion

Data are presented for six species tested in static water (fig. 17): the centracanthid, Pterosmaris axillaris; the sparids, Pachymetopon blochi and Species 5; the cynoglossid, Trulla capensis; the gadid, Gaidropsarus capensis; and the conglopodid, Conglopodus spinifer; and two species tested with the flow-through apparatus (fig. 18): the soleid, Heteromycteris capensis; and the gadid, Gaidropsarus capensis. A tabular summary of these results is included in table 7, along with selected results of other authors.

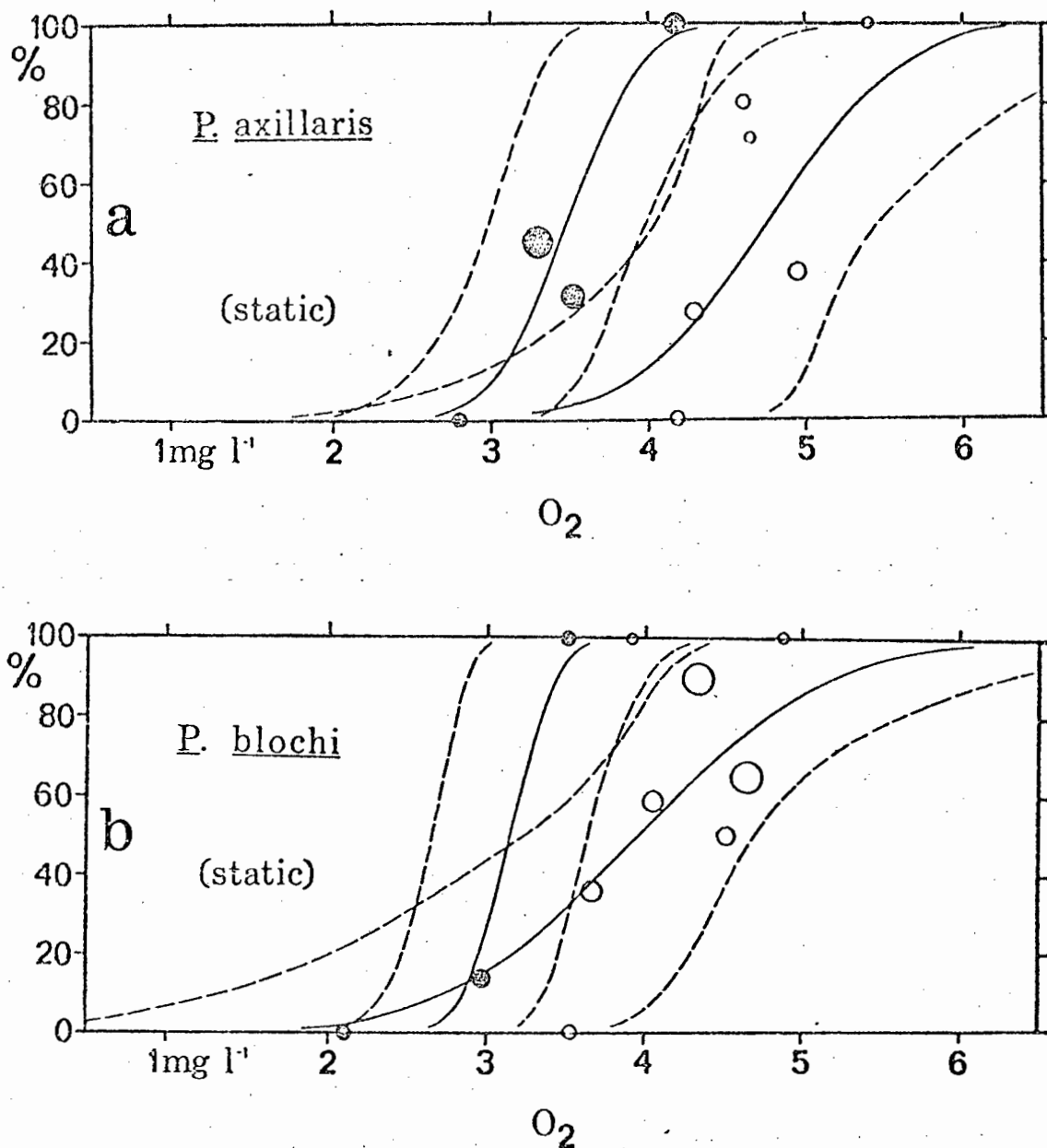


Figure 17. Response of first-feeding (a) *Pterosmaris axillaris*, (b) *Pachymetopon blochi*, (c) *Species 5*, (d) *Trulla capensis*, (e) *Gaidropsarus capensis*, and (f) *Congiopodus spinifer* to low DO under static conditions. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various low dissolved oxygen concentrations. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding DO concentrations. The solid curves were fitted by assuming a normal distribution of tolerance over un-transformed units of DO concentration. 95% confidence limits are represented by dashed lines.

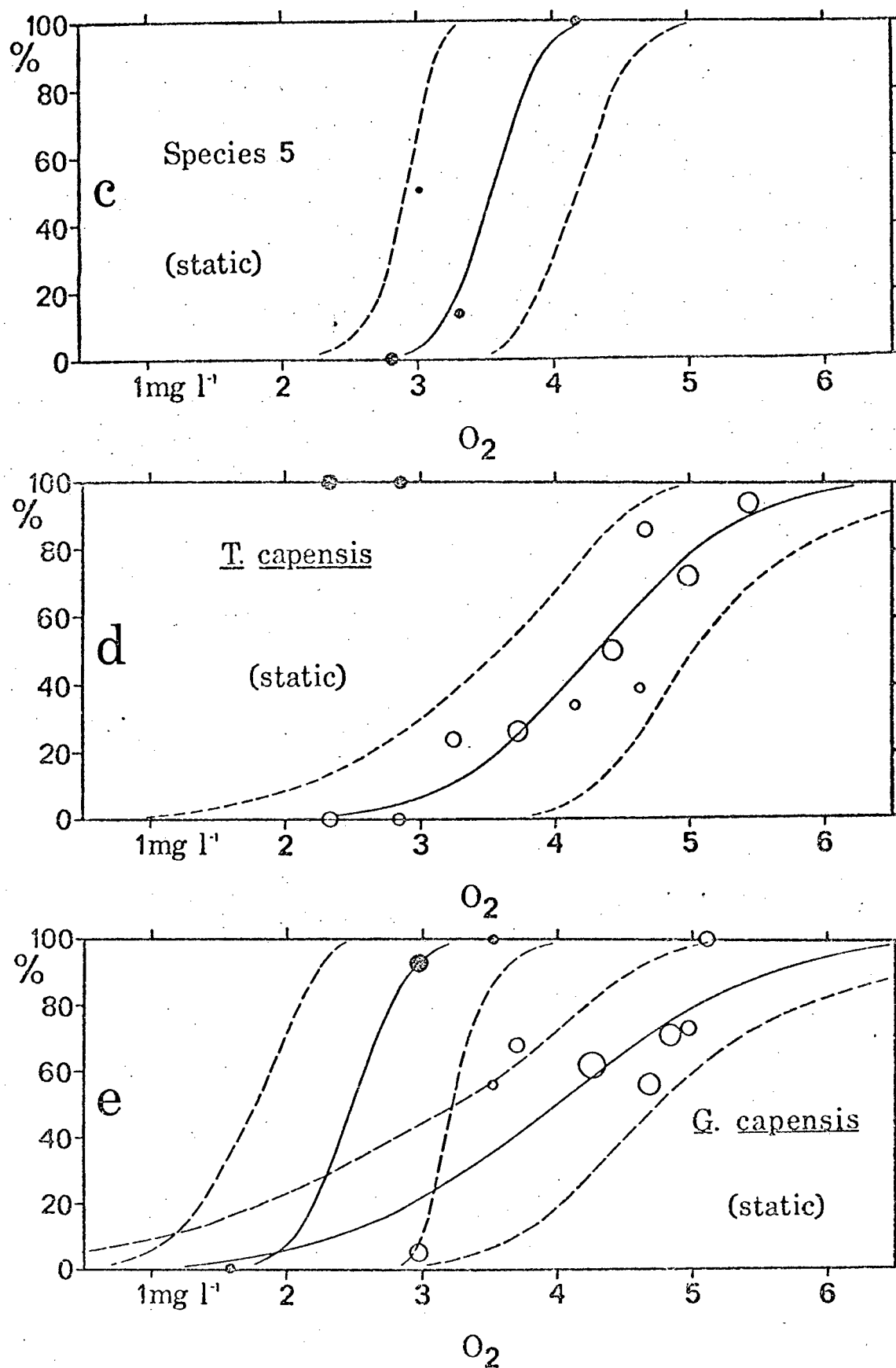


Figure 17. (continued)

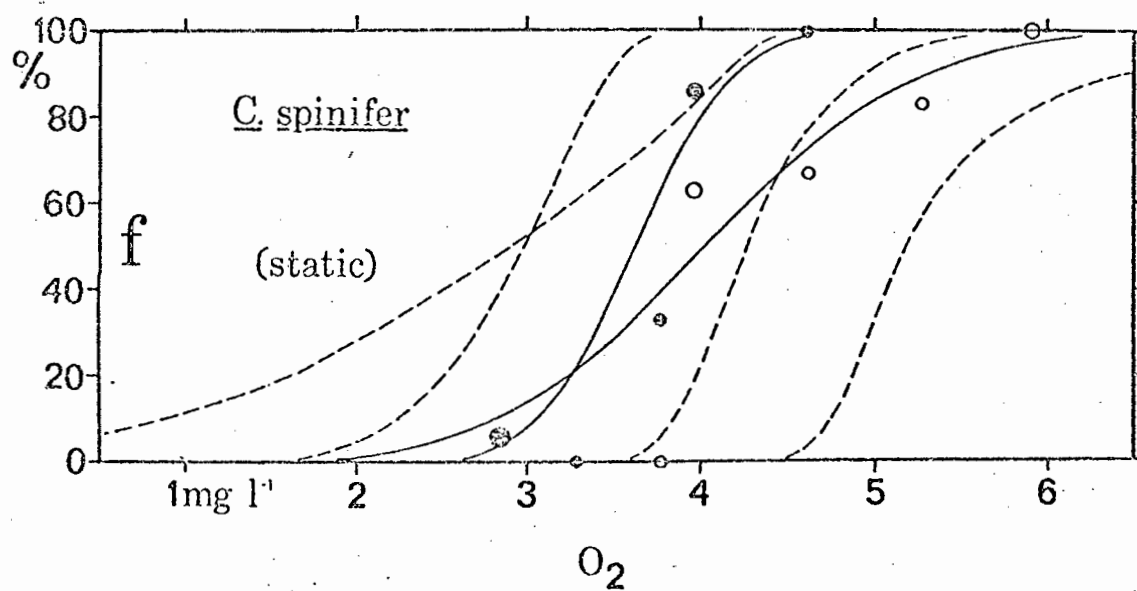


Figure 17. (continued)

For some of the EC50 data, the regression of probit response on DO concentration yielded lines that underestimate the tolerance of the larvae to higher DO and overestimate their tolerance to lower DO. In other words, the slope of the calculated response curve is clearly less than that of an eye-drawn curve through the raw data. This is particularly evident in fig. 17a, b, & e. The low weighting coefficients that are assigned to extreme response rates in maximum likelihood estimation are partially responsible for this state of affairs; the somewhat horizontal distribution of data points in the area of median response provides the rest of the explanation. Rather substantial Chi-squares (fig. 17a: 11,7 with 4 d.f.; fig. 17b: 18,4 with 6 d.f.; fig 17e: 14,7 with 6 d.f.) were incurred in fitting some of the first-feeding EC curves graphed, and although the values near the 50% response percentile are probably meaningful, caution should be exercised in predicting the response at more extreme percentiles.

Very generally speaking, first-feeding incidence was reduced by 50%, in a static situation, when the DO concentration of the water mass was between about 4,0 and 4,75 mg l⁻¹. All five of the species tested in static water (no feeding data is presented for Species 5) yielded 24-h first-feeding EC50's in this range. The DO concentration at which first-feeding "begins" to be affected seems to fall somewhere between 5,0 and 5,5 mg l⁻¹ for these same species. Under conditions of temperature and salinity employed, these values correspond to air-saturation percentages of 49-58% (4,0-4,75 mg l⁻¹) and 62-68% (5,0-5,5 mg l⁻¹) (Weiss, 1970). 24-h LC50's under static conditions were quite low in the case of the cynoglossid (<2,3 mg l⁻¹) and the gadid (2,5 mg l⁻¹), but higher for the perciform species (3,2-3,6 mg l⁻¹) and the conglopodid (3,6 mg l⁻¹).

Trials with the flow-through apparatus yielded somewhat

different results (fig. 18). The EC50 (flow-through) for the gadid was 3,2 (2,4-3,9) mg l⁻¹, whereas the EC50 (static) was 4,0 (3,3-4,8); the LC50 (flow-through) was 2,1 (1,6-2,6), and LC50 (static) was 2,5 (1,8-3,2). The 95% confidence intervals overlap in both cases, however, and more trials would be required to determine how consistent the differences really are. On theoretical grounds, it would not be surprising that the tolerance to low DO in turbulence is greater than that in a static body of water of the same mean DO concentration. The relationship between DO, current speed, and growth/survival in salmonid eggs was investigated by Silver et al. (1963), Shumway et al. (1964), and Daykin (1965). The latter employed the principles of mass transfer to quantitatively account for the observed influence of DO and current speed on embryonic development. Although first-feeding larvae, unlike eggs, are motile, they do alternate between states of activity and rest (e.g. Schumann, 1965; Hunter, 1972). During periods of inactivity, the larvae would act as oxygen-sinks, in the same manner as eggs, creating a slightly de-oxygenated micro-environment. In the case of herring (Clupea harengus) and plaice (Pleuronectes platessa) larvae, at least (De Silva & Tytler, 1973), there is a compensatory decline in O₂ uptake at lowered DO levels. The decline in metabolic rate seems to be achieved by a decrease in activity. It is clear that in non-turbulent water, any decline in activity would enhance the oxygen-sink effect; in turbulent water, a decline in activity might be negligible. Successful first-feeding requires considerable activity.

A comparison of the present results with those obtained for other marine teleost larvae, for marine teleost eggs, and for selected freshwater teleost larvae, is facilitated by table 7. The three intertidal/estuarine species tested by Saksena & Joseph (1972) using flow-through procedures yielded 24-h LC50's comparable to those of Gaidropsarus

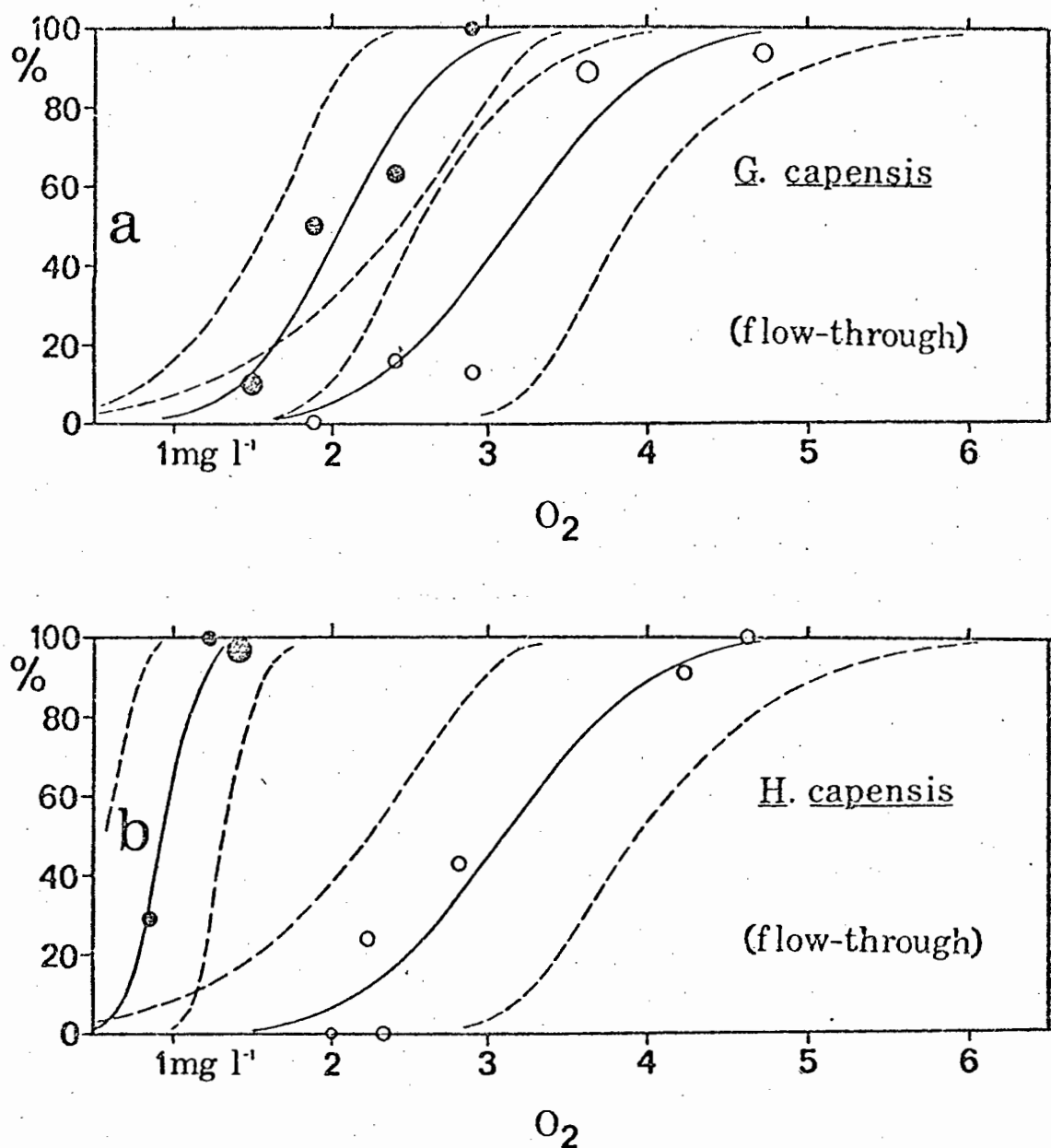


Figure 18. Response of first-feeding (a) *Gaidropsarus capensis* and (b) *Heteromycteris capensis* to low DO under flow-through conditions. Open circles represent raw data (adjusted, when necessary, for natural responsiveness) on first-feeding incidence following 24-h exposure to various low dissolved oxygen concentrations. Solid circles represent data on percent survival during 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding DO concentrations. The solid curves were fitted by assuming a normal distribution of tolerance over un-transformed units of DO concentration. 95% confidence limits are represented by dashed lines.

Table 7. Selected data on the response of some teleost eggs and larvae to low dissolved oxygen. (A) Marine teleost larvae. (B) Marine teleost eggs. (C) Freshwater teleost (non-salmonid) larvae.

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰ S)	temp. (°C)	response	test type	reference
			A. Marine teleost larvae				
1,6	<u>Cyclopterus lumpus</u> (lumpsucker)	larva: 21 d post-hatch	34	12,7	death within 1 h	flow-through	Bishai, 1959
2,6	"	larva: 20 d post-hatch	"	"	survived for at least 6 h	"	"
3,7	"	larva: 22-24 d post-hatch	"	"	50-80% survival after 24-h exposure	"	"
2,3-2,7	<u>Clupea harengus</u> (herring)	larva: newly hatched	"	14	"activity begins to be restricted" after 24-h exposure	flow-through and static	"
4,6-5,3	"	larva: 3-4 d post-hatch	"	"	"	"	"
5,5	<u>Paralichthys lethostigma</u> (southern flounder)	larva: 8-11 mm SL	32-32,5	14,4	the highest DO conc. from which larvae withdrew when they swam from an O ₂ -saturated zone into a zone of low O ₂	gradient: see original publication	Deubler & Posner, 1963
0,7-1,2	<u>Gobiosoma</u> (skilletfish)	larva: newly hatched	19,8-20,7	20,0 21,7	24-h LC50	flow-through	Saksena & Joseph, 1972
1,3 (1,1-1,5)	<u>Gobiosoma bosci</u> (naked goby)	"	"	"	"	"	"
2,5 (2,1-3,1)	<u>Chasmodes bosquianus</u> (striped blenny)	"	"	"	"	"	"
2,8 (2,4-3,1)	<u>Clupea harengus</u>	larva: 1-8 d post-hatch	sea water	8-13	12-h LC50	"	De Silva & Tytler, 1973
4,4 (3,6-5,4)	"	larva: 21-28 d post-hatch	"	"	"	"	"
5,1 (4,8-5,4)	"	larva: 42-49 d post-hatch	"	"	"	"	"
4,2 (3,8-4,6)	"	larva: 56-63 d post-hatch	"	"	"	"	"

Table 7. (continued)

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰ S)	temp. (°C)	response	test type	reference
3,1 (2,9-3,3)	<u>Clupea harengus</u>	metamorphosed: 70-80 d post-hatch	sea water	8-13	12-h LC50	flow-through	De Silva & Tytler, 1973
3,9 (3,6-4,2)	<u>Pleuronectes platessa</u> (plaice)	larva: 1-8 d post-hatch	"	"	"	"	"
3,8 (3,5-4,2)	"	larva: 21-28 d post-hatch	"	"	"	"	"
3,6 (3,4-3,9)	"	larva: 42-49 d post-hatch	"	"	"	"	"
2,4 (2,3-2,6)	"	metamorphosed: 77-84 d post-hatch	"	"	"	"	"
4,0 (3,2-4,8) ¹	<u>Mugil cephalus</u> (grey mullet)	larva: exposure begun within 8 h post-hatch	32	19,5-20,5	0% survival after 24 h	flow-through	Sylvester et al., 1975
4,8 (4,3-5,3) ¹	"	"	"	"	7-29% survival after 24 h, 0% after 96 h	"	"
5,4 (5,0-5,8) ¹	"	"	"	"	100% survival after 24 h, 0-16% after 96 h	"	"
6,4 (5,9-6,9) ¹	"	"	"	"	93-99% survival after 24 h, 12-30% after 96 h	"	"
7,9 (7,7-8,1) ¹	"	"	"	"	91-99% survival after 24 h, 79-89% after 96 h	"	"
4,1-4,3	<u>Dicentrarchus labrax</u> (seabass)	larva: age not specified	35	17-19	no mortalities were observed when DO dropped to this level in rearing tank	(observation)	Girin, 1976
4,8 (4,1-5,5)	<u>Pterommaris axillaris</u> (windtoy)	first-feeding larva	35	15	24-h first-feeding EC50	static	(this study)
3,5 (3,0-4,0)	"	"	"	"	24-h LC50	"	"

Footnotes: 1. These values are taken from the third column, Table V, of Sylvester et al. (1975). Errors in their publication have resulted in contradictions between the third column and the first or second.

Table 7. (continued)

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰ S)	temp. (°C)	response	test type	references
4,0 (3,2-4,7)	<u>Pachymetopon</u> <u>blochi</u> (hottentot)	first-feeding larva	35	15	24-h first-feeding EC50	static	this study
3,2 (2,7-3,7)	"	"	"	"	24-h LC50	"	"
3,6 (2,9-4,2)	Species 5 (unidentified)	"	"	"	"	"	"
4,3 (3,6-5,0)	<u>Trulla capensis</u> (sand tonguefish)	"	"	"	24-h first-feeding EC50	"	"
<2,3	"	"	"	"	24-h LC50	"	"
4,0 (3,3-3,8)	<u>Gaidropsarus</u> <u>cabensis</u> (Cape rockling)	"	"	"	24-h first-feeding EC50	"	"
2,5 (1,8-3,2)	"	"	"	"	24-h LC50	"	"
3,2 (2,4-3,9)	"	"	"	"	24-h first-feeding EC50	flow-through	"
2,1 (1,6-2,6)	"	"	"	"	24-h LC50	"	"
4,0 (2,9-5,2)	<u>Congloporus</u> <u>spinifer</u> (spinenose horsefish)	"	"	"	24-h first-feeding EC50	static	"
3,6 (3,0-4,3)	"	"	"	"	24-h LC50	"	"
3,1 (2,3-3,9)	<u>Heteromyceteris</u> <u>cabensis</u> (Cape sole)	"	"	"	24-h first-feeding EC50	flow-through	"
0,9 (0,6-1,3)	"	"	"	"	24-h LC50	"	"

Table 7. (continued)

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰)	temp. (°C)	response	test type	references
B. Marine teleost eggs							
3	<u>Gadus macrocephalus</u> (Pacific cod)	egg: from 1 h after fertilization to hatching	15	3-4,5	near-maximum (90%) viable hatch at this and higher DO concentrations	flow-through	Alderdice & Forrester, 1971 (their fig. 9)
2,4	<u>Fundulus heteroclitus</u> (mummichog)	egg: shortly after fertilization to hatching	30-32	20	survival to 14 days post-fertilization was 80% that of control; survival through hatching was 10%	"	Voyer & Hennekey, 1972
4,5	"	"	"	"	survival to 14 days post-fertilization was 99% that of control; survival through hatching was 72%	"	"
2,2	<u>Clupea harengus</u> (herring)	egg: shortly after fertilization to hatching	15	8	0% hatch	"	Braun, 1973
5,4	"	"	"	"	reduction in mean body length of newly-hatched larva	"	"
3,5 (2,7-4,3) ²	<u>Mugil cephalus</u> (grey mullet)	egg	32	19,5-20,5	2-8% survival after 24 h, 0% survival after 48 h	"	Sylvester et al., 1975
4,5 (3,7-5,3) ²	"	"	"	"	13-21% survival after 24 h, 1-5% survival after 48 h	"	"
5,0 (4,5-5,5) ²	"	"	"	"	81-94% survival after 24 h, 83-87% survival after 48 h	"	"
2,1	<u>Sardinops ocellata</u> (S. Afr. pilchard)	egg: blastodisc stage to hatching	33-36	18-22	78-90% viable hatch (about 84% that of control)	"	Kins, 1977
5,0	"	"	"	"	84-92% viable hatch (same as control)	"	"
C. Freshwater teleost (non-salmonid) larvae							
2 (1,8-2,2)	<u>Pimephales promelas</u> (fathead minnow)	entire generation	fresh water	about 20-25	most larvae died within 2-5 d post-hatch, all within 13 d	"	Brungs, 1971

Footnotes: 2. These values are taken from the third column, Table III, of Sylvester et al. (1975). Errors in their publication have resulted in contradictions between the third column and the first or second.

Table 7. (continued).

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰S)	temp. (°C)	response	test type	references
3 (2,7-3,3)	<u>Pimephales promelas</u> (fathead minnow)	entire generation	fresh water	about 20-25	% survival at 30 days post-hatch was 11% that of the controls	flow-through	Brunas, 1971
4 (3,6-4,4)	"	"	"	"	% survival to 30 days post-hatch was 48% that of the controls; growth was significantly less (p<.01)	"	"
5 (4,5-5,5)	"	"	"	"	% survival to 30 days post-hatch was slightly better than that of the controls, but growth was significantly less	"	"
1,3 (1,1-1,5)	<u>Esox lucius</u> (northern pike)	egg and larva to 20 d post-fertilization	"	15	% survival was similar to that of control until about the 12th d post-fertilization (2-4th d post-hatch), but all died during the next 6 d, prior to feeding	"	Siefert et al., 1973
2,6 (2,3-3,0)	"	"	"	"	% survival was similar to that of control until first-feeding, when 80% died over the next 12 h	"	"
3,2 (2,6-3,5) & 3,4 (2,9-3,7)	"	"	"	"	% survival dropped by half at first-feeding in 3,2 mg l ⁻¹ group, but not in 3,4 mg l ⁻¹ group	"	"
4,9 (4,4-5,3)	"	"	"	"	% survival not different from that of control	"	"
1,2 (1,1-1,3)	<u>Micropterus dolomieu</u> (smallmouth bass)	egg and larva to 14 d post-fertilization	"	20	0% hatch	"	Siefert et al., 1974
2,5 (2,4-2,8)	"	"	"	"	hatching was successful, but no hatchlings survived to first-feeding	"	"
4,4 (4,2-4,8)	"	"	"	"	first-feeding apparently successful, but average length at 10-12 d post-hatch was 0,6 mm (5%) less than that of controls	"	"

Table 7. (continued)

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰ S)	temp. (°C)	response	test type	references
1,8 (1,6-2,0)	<u>Morone chrysops</u> (white bass)	egg and larva to 11 d post-fertilization	"	16	% hatch not different from that of control, but during the next 7 d, survival dropped to 63% that of the control	flow-through	Siefert et al, 1974
3,4 (3,1-3,7)	"	"	"	19	reported food-searching behavior at this and higher DO concentrations tested	"	"
1,2 (1,0-1,5)	<u>Catostomus commersoni</u> (white sucker)	egg and larva to 22 d post-fertilization	"	18	0% hatch	"	Siefert & Spoor, 1974
2,5 (2,3-2,8)	"	"	"	"	first-feeding successful (?), but growth much less than control	"	"
4,9 (4,6-5,2)	"	"	"	"	growth and survival not different from that of control	"	"
2,4 (2,1-2,9)	<u>Stizostedion vitreum</u> (walleye)	egg and larva to 20 d post-fertilization	"	17	more than 1/2 died during embryonic stage, all hatchlings died prior to first-feeding	"	"
3,4 (2,7-3,9)	"	"	"	"	mean survival at test end was 35% that of control; most of this mortality occurred during pre-feeding larval stage	"	"
4,8 (4,0-5,0)	"	"	"	"	growth and survival not appreciably different from that of control	"	"
1,7 (1,4-1,7)	<u>Micropterus salmoides</u> (largemouth bass)	egg and larva to 20 d post-fertilization	"	20	survival after 20 days was less than 1% that of control; first-feeding delayed about 27 h	"	Carlson & Siefert, 1974
3,1 (2,8-3,5)	"	"	"	"	survival after 20 days was slightly less than that of control; first-feeding delayed 11-23 h	"	"
4,5 (4,1-5,1)	"	"	"	"	survival not different from control but average growth slightly less	"	"

Table 7. (continued)

dissolved oxygen concentration (mg l ⁻¹)	species	stage in life history exposed	salinity (‰S)	temp. (°C)	response	test type	references
2.4 (2,1-3,3)	<u>Ictalurus punctatus</u> (channel catfish)	egg and larva to 19 d post-hatch	fresh water	25	mean % hatch was 25% that of control; % survival of hatchlings to 19 d was 45% that of control	flow-through	Carlson et al., 1974
4.2 (3,8-4,4)	"	"	"	"	mean % hatch was 59% that of control; % survival of hatchlings to 19 d was 95% that of control	"	"
5.0 (3,8-5,4)	"	"	"	"	growth and survival slightly less than that of control; first-feeding was delayed by about 1 d	"	"
2.7 (2,2-3,4)	<u>Pomoxis nigromaculatus</u> (black crappie)	egg and larva to swim-up	"	13-20	"little or no discernable effect on...viability, hatching success, and survival through the swim-up stage"	"	Siefert & Herman, 1977: 377

capensis and Heteromycteris capensis, also using flow-through apparatus. The DO concentrations lethal to feeding herring and plaice larvae (De Silva & Tytler, 1973) and grey mullet larvae (0-96 h post-hatch) (Sylvester et al., 1975) seem to be higher: they are closer to the range of concentrations obtained during the present study using static techniques. Neither of these publications provided information on the rate of exchange of water in experimental containers and it is not clear whether differences are due to dissimilar techniques or to real, specific differences in physiological tolerance.

A loss of appetite and/or decrease in growth rate in fish exposed to low DO has been noted by a number of authors. In some experiments, only slight depressions of DO below air-saturation resulted in noticeable decrease in growth relative to controls (Herrmann et al., 1962: Oncorhynchus); in others (Carter & Allen, 1976: Ictalurus), much greater depressions (to about 3 mg l⁻¹) were required. Adult black crappie (Pomoxis nigromaculatus) still fed well, and successfully spawned, at long-term DO levels of about 2.7 mg l⁻¹ (Siefert & Herman, 1977). For most of the marine larvae studied here, there was not a great difference between the 24-h first-feeding EC50 and the 24-h LC50. The two pleuronectiformes (Heteromycteris and Trulla) were exceptions.

The question as to which stage in a fish's life cycle is most sensitive to hypoxia cannot be satisfactorily answered at present. Based on studies of freshwater species, Doudoroff & Shumway (1970) concluded that the juvenile stage was, in general, the most tolerant. A comparison of experimentally-determined tolerance limits at various life stages supports (but not always clearly) the proposition that larval stages are less tolerant than either eggs or juveniles: (mentioning only non-salmonids) compare Carlson et al. (1974: Ictalurus eggs and larvae) to Moss & Scott (1961: Ictalurus juveniles); compare Turner & Farley

(1971: Morone saxatilis eggs and larvae) to Chittenden (1971: M. saxatilis juveniles); compare Siefert et al. (1974: Morone chrysops eggs and larvae) to Mount (1961: M. chrysops juveniles); compare Braum (1973: Clupea eggs) to De Silva & Tytler (1973: Clupea larvae); and Brungs (1971: Pimephales, all stages). At present, information is too fragmentary to permit generalization as to which point during the larval phase might be most sensitive to hypoxia. Siefert et al. (1973: Esox) doubted that DO concentrations just sufficient for survival through the yolk-sac stage would ensure survival through first-feeding. Results of the study by De Silva & Tytler (1973) on the effect of low DO to various stages of larval plaice and herring imply that tolerance is fairly high in the yolk-sac stage, decreases during the period of cutaneous respiration, and increases again after the onset of branchial respiration. A few studies have been published on the morphometrics of developing gill structures of fish larvae from small eggs (i.e. where branchial respiration develops only after yolk-absorption), and the results may help to explain ontological variation in tolerance. De Silva (1974) related total surface area (including developing gills) to wet mass in herring and plaice larvae. From equations provided in his figure 11, it may be calculated that during the period of growth from 5 to 50 mg, the surface-area/wet-mass ratio decreases, from 11,6 to 4,5 mm² mg⁻¹ in the herring, and from 10,6 to 3,4 mm² mg⁻¹ in the plaice. The increasing efficiency of branchial respiration (notably by the synthesis of haemoglobin and appearance of blood corpuscles) must largely compensate for the declining ratio. Iwai & Hughes (1977) plotted the change in ratio of an index of gill filament area to an index of gill filament volume in larvae of the black seabream (Acanthopagrus schlegelii) during the first 25 days post-hatch. The ratio was found to be minimal during the first-feeding stage. Nevertheless, there appears to be no direct evidence that the DO concentration required for first-feeding is any higher (or lower) than that required for subsequent, pre-branchial feeding.

4.8 CO₂

4.8.1 Specific methods

Larvae of one species (Heteromycteris capensis) were exposed to a range of free CO₂ concentrations from 0,46 mg l⁻¹ to 7,70 mg l⁻¹ CO₂-C. Elevated CO₂ concentrations were achieved by first increasing the alkalinity of system water by adding varying amounts of 0,4 M Na₂CO₃, then reducing the pH to 7,1-7,2 with 0,8 N HCl. It had already been established that, as long as CO₂ is in atmospheric equilibrium, first-feeding in H. capensis is not impaired by a 24-h exposure to pH 7,1, nor by bicarbonate concentrations of that of the most extreme treatment group tested, i.e. 8,9 mmol l⁻¹.

The tests were static. The test containers were fitted with screened bungs with a wad of synthetic wool, turned on their sides, and left for 24 h. As usual, food was added and larvae were given 4 h to feed. After rating and removing larvae, the final pH was measured and the total alkalinity was determined by titration with 0,010 N HCl. The nominal concentration of free CO₂ was taken as the amount calculated to be present at the end of the experiment.

The relationships required for evaluation of the carbonate system in sea water were taken from Park (1969), to which the following constants were applied (15°C, 35‰S): first apparent dissociation constant of carbonic acid, $K_1' = 8,73 \times 10^{-7}$; second apparent dissociation constant of carbonic acid, $K_2' = 5,58 \times 10^{-10}$ (Mehrbach et al., 1973); first apparent dissociation constant of boric acid, $K_B' = 1,62 \times 10^{-9}$ (from Lyman, 1957, published by Skirrow, 1965). The concentration of borate in the water was assumed to be similar to that of oceanic water of equivalent chlorinity, i.e., 0,4 mmol l⁻¹ (Hansson, 1973).

4.8.2 Results and discussion

The results of an experiment with the Cape sole, Heteromycteris capensis, are presented in table 8.

Table 8. Results of an experiment in which first-feeding Heteromycteris capensis were exposed to free CO₂ concentrations of 0,46 (control) to 7,70 mg l⁻¹ CO₂-C. There were no mortalities during the 28-h exposure and all groups fed about equally well.

	pH at end	total alkalinity (meq l ⁻¹)	HCO ₃ -C (mg l ⁻¹)	CO ₃ -C (mg l ⁻¹)	CO ₂ -C (mg l ⁻¹)	number of larvae with..				Σn	% "fed"
						gut full	gut ½-full	gut nearly empty	gut empty		
control	7,83	2,45	26,89	1,02	0,46	18	2	0	1	21	95
treatment 1	7,09	0,75	8,79	0,06	0,82	12	5	1	1	19	89
treatment 2	7,16	3,60	42,41	0,34	3,36	15	4	3	0	22	86
treatment 3	7,17	6,00	70,72	0,58	5,48	16	4	0	2	22	91
treatment 4	7,20	9,05	106,59	0,94	7,70	14	4	1	1	20	90

There were no noteworthy differences in first-feeding incidence between the control and any of the treatments. The highest level of CO₂ tested was 7,70 mg l⁻¹ CO₂-C, which corresponds to 28 mg l⁻¹ CO₂, or a pCO₂ of 1,69 kPa under the conditions specified (solubility of CO₂ in sea water from Murray & Riley, 1971).

Levels of free CO₂ that have been reported to adversely affect fish range very widely. Doudoroff & Katz (1950:1447) concluded that free CO₂ concentrations between 27 and 55 mg l⁻¹ CO₂-C (=100-200 mg l⁻¹ CO₂) are "rapidly lethal to the more sensitive freshwater fishes in the presence of dissolved oxygen concentrations which are usually deemed quite adequate", and that concentrations between 14 and 27 mg l⁻¹ CO₂-C (=50-100 mg l⁻¹ CO₂), or even lower, "may be lethal after prolonged exposure, or when associated with an

abnormally low, though not ordinarily lethal, oxygen tension." Doudoroff (1957:412) noted that free CO_2 concentrations above $5.5 \text{ mg l}^{-1} \text{ CO}_2\text{-C}$ ($=20 \text{ mg l}^{-1} \text{ CO}_2$) "occur rarely, even in polluted waters."

The only study encountered on the tolerance of marine fish eggs or larvae to free CO_2 was that of Kelley (1946), who incubated herring (Clupea harengus pallasii) eggs in the presence of elevated CO_2 (achieved by bubbling CO_2 gas into incoming water). She reported a serious retardation in embryonic development and failure to hatch. Wide variation in the exposure concentration ($2.1\text{--}18.5 \text{ mg l}^{-1} \text{ CO}_2\text{-C}$) and pH ($5.12\text{--}7.88$) detract from the usefulness of the data. Putnam (1967) found that an exposure of rainbow trout eggs during the entire incubation period to $7.7 \text{ mg l}^{-1} \text{ CO}_2\text{-C}$ had little or no effect on the mass of the newly-hatched larvae (minus yolk) as long as dissolved oxygen was adequate.

The Cape sole is admittedly one of the more rugged of the 10 species of larvae used in these studies—and one cannot automatically rule out the possibility that first-feeding in one of the other species would have been affected at the highest concentrations tested. Still, $7.7 \text{ mg l}^{-1} \text{ CO}_2\text{-C}$ is well above the levels of free CO_2 likely to be present in any fish tank. Because excess CO_2 is lost to the atmosphere through the same procedures by which DO is introduced, the chances that free CO_2 could become the primary limiting factor in an adequately oxygenated rearing tank are extremely remote.

4.9 Combination of O_2 and NH_3

4.9.1 Special methods

A single concentration of ammonia was tested in combination with nine concentrations of DO to determine the effect on first-feeding in the Cape rockling, Gaidropsarus capensis. The ammonia concentration used was $0.066 \text{ mg l}^{-1} \text{ NH}_3\text{-N}$ (un-ionized), which is the level expected to reduce

first-feeding incidence by 10% in this species. The required amount of NH_4Cl stock solution was micropipetted into a quantity of system water. Dissolved oxygen in treatments was then reduced by nitrogen stripping. The control group was exposed to the same ammonia concentration, but with dissolved oxygen near saturation. Analysis of the results was done in the same fashion as described in the previous section (O_2 , static), except that the response curve was based on the assumption that first-feeding incidence asymptotically approached 90%, rather than 100%.

4.9.2 Results and discussion

In unadulterated system water de-oxygenated to varying degrees, the gadid, Gaidropsarus capensis, yielded a 24-h first-feeding EC_{50} (static) of 4,0 (3,3-4,8) $\text{mg l}^{-1} \text{O}_2$ (fig. 17e). When 0,066 $\text{mg l}^{-1} \text{NH}_3\text{-N}$ (un-ionized) (the amount calculated to reduce first-feeding incidence by 10% when DO is near saturation), was added to the water, the 24-h first-feeding EC_{50} (static) was increased to 5,0 (4,2-5,9) $\text{mg l}^{-1} \text{O}_2$ (fig. 19).

In view of the overlapping of the 95% confidence limits of the two response curves, the difference between 4,0 and 5,0 mg l^{-1} in this case cannot be termed substantial. If the sublethal toxicity of ammonia to these larvae were entirely explicable by impairment of respiratory function (as has been hypothesized for juvenile salmonids (Sousa & Meade, 1977: Oncorhynchus), one might have expected a much more decisive effect on dissolved oxygen requirements for first-feeding. The toxic mechanism proposed by Sousa & Meade involves chronic acidemia, resulting in methaemoglobinaemia. This pathway cannot apply to larvae at pre-haemoglobin stages, nor, according to Smart (1978: Salmo) to haemoglobin stages exposed to acutely lethal ammonia concentrations.

The results of the above experiment provide evidence that first-feeding is more inhibited by a combination of sub-optimal levels of ammonia and dissolved oxygen than by the same levels tested independently (as would be expected from similar findings in juvenile freshwater fish (e.g. Downing & Merkins, 1955: Salmo). The results do not provide evidence that potentiation is involved in the response of marine fish larvae to simultaneous exposure to sublethal ammonia and dissolved oxygen concentrations.

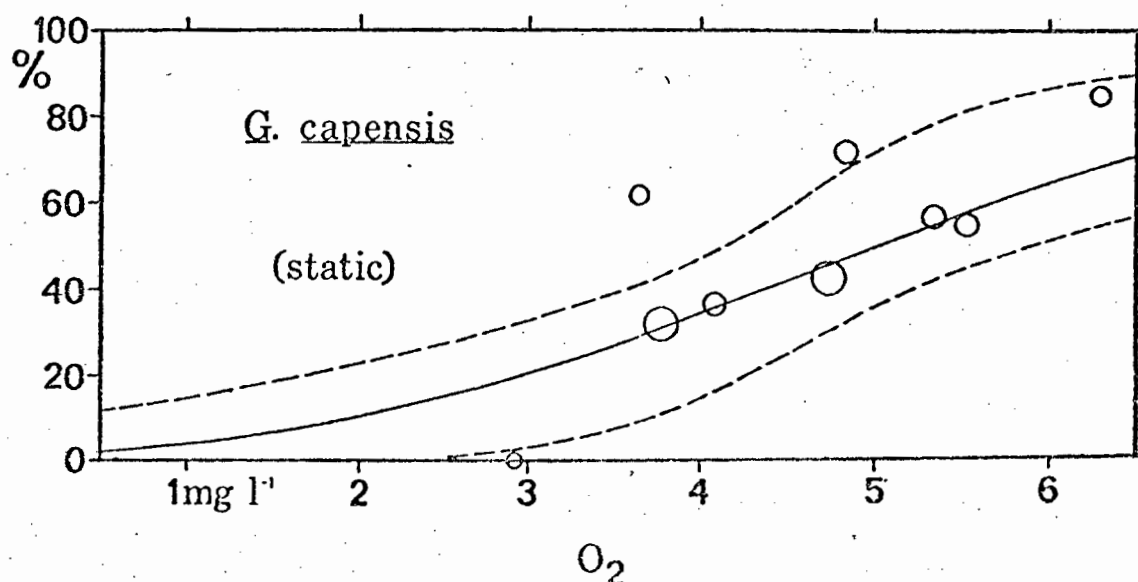


Figure 19. Response of first-feeding Gaidropsarus capensis to a combination of un-ionized ammonia (EC10: 0,066 mg l⁻¹ NH₃-N) and nine reduced DO concentrations. Circles represent raw data (adjusted for natural responsiveness) on first-feeding incidence following 24-h exposure. The areas of the circles are proportional to the number of larvae tested at corresponding DO concentrations. The curve was fitted by assuming a maximum feeding incidence of 90% and a normal distribution of tolerance over un-transformed units of DO concentration. 95% confidence limits are represented by dashed lines.

5. GENERAL DISCUSSION

The first-feeding response can be a powerful tool in establishing criteria for survival of fish larvae. Lasker (1975) used it to assay the availability of food for larval northern anchovy (Engraulis mordax) at sea. He placed previously unfed, laboratory-hatched larvae in vessels containing the sea water to be assayed, gave them 8 h in which to feed, and then examined the contents of the gut. The incidence of feeding was positively correlated with the abundance of certain particles in the sea water. First-feeding bioassays of this type are being undertaken at several laboratories (Hunter, 1976a). The two principal advantages of using the first-feeding stage rather than later stages are that (1) the gut is empty at the beginning of the experiment, obviating the need for a preliminary period of starvation or labeling of food, and (2) the pre-test history of the larvae can be more confidently controlled, thus increasing the likelihood of using uniformly healthy experimental animals. The two principal disadvantages of using the first-feeding stage are (1) the extreme fragility of the larvae, and (2) the necessity of timing the feeding test between the point when the larvae are mature enough to first-feed and the point when first-feeding success begins to decline because of starvation-induced degeneration. This period is highly temperature- and species-dependent, and must therefore be carefully determined in advance. Such factors as the size and shape of the test container, the amount and direction of light, and the degree of contrast between the food and the background, can be as important as the food itself.

The inhibition of first-feeding is probably not the most sensitive indicator of stress in fish larvae—no doubt much more sensitive behavioral or physiological responses will eventually be recognized. It is, nevertheless, a highly relevant response, in that death by starvation is the

inevitable consequence.

Of the seven variables tested here as potential inhibitors of first-feeding, only un-ionized ammonia, high pH, and low dissolved oxygen concentration were found to pose material hazards for the marine fish nurseryman. Nitrite, nitrate, hydrogen ion, and carbon dioxide only affected first-feeding success at concentrations well above those expected to occur naturally in practical marine pisciculture.

The relative tolerances of marine and freshwater fish to the seven variables under discussion are difficult to assess on the basis of data now available. Although nitrite is highly toxic to freshwater fish (particularly in waters deficient in chloride and calcium ions (Wedemeyer & Yasutake, 1978)), it was clearly nontoxic to the marine larvae tested here. Nitrate appears to be even less toxic to marine fish larvae than to freshwater fish. Lowering the pH of normal sea water to 6.0 yields a solution lethal to fish larvae if the excess carbon dioxide released by the addition of acid is not adequately dissipated. In acidified sea water where dissolved carbon dioxide is in equilibrium with atmospheric carbon dioxide, a 24-h exposure to pH 6.0 negligibly affected first-feeding success. A similar situation appears to prevail in alkaline fresh waters. The gradual decline of pH characteristic of recirculated culture water is not likely to be accompanied by free carbon dioxide concentrations much above atmospheric equilibrium levels. In any case, even substantial ($7.7 \text{ mg l}^{-1} \text{ CO}_2\text{-C}$) levels of free carbon dioxide did not affect first-feeding in the Cape sole, Heteromycteris capensis. First-feeding was inhibited by levels of un-ionized ammonia, high pH, and low dissolved oxygen that could very easily be experienced in a rearing tank. The tolerance of marine fish larvae at the first-feeding stage to these stressors appears to be equal to, or slightly less than, that of freshwater fish larvae.

Although attention is directed to the potential danger of inadequate control of ammonia, high pH, and dissolved oxygen,

it is clear that other reasons must be found to account for failure of some larvae to feed in captivity. In the present study, approximately 20% of all tolerance experiments were rejected because the feeding incidence in control groups was below an arbitrary 50%. Mean control feeding incidence in the remainder was 74,8%. Certain species (Heteromycteris capensis, Gaidropsarus capensis, Pachymetopon blochi, and Congiopodus spinifer) only rarely yielded control feeding incidences below 50%; others (Trulla capensis and Synaptura kleini) often fell below 50% but occasionally approached 100%. In the bioassay experiments conducted by Lasker (1975), control feeding incidence (defined as the presence of more than 8 particles in the gut at the end of an 8-h exposure to food) ranged from 27 to 32%. About the same percentage had 1-8 particles of food in the gut. The remainder had consumed no food at all. A consumption rate of at least one particle per hour had been established in the laboratory as the minimum for survival.

Whether to attribute the often high degree of first-feeding incompetence to factors related to the captive situation, or to blame fundamental disfunction, is a difficult decision at this time. There is tremendous scope for future work on both environmental and genetic factors that influence the ability of a marine fish larva to ingest its first particle of food.

6. SUMMARY

1. Previously unfed larvae of ten species of marine teleosts were exposed for 24 h to various sub-optimal conditions and then tested for their ability to first-feed. Mortalities recorded during the 24-h exposure went into the calculation of an LC50 and LC10 (concentrations of the variable that killed 50% and 10%, respectively). The incidence of successful first-feeding during the subsequent 4-h exposure to food yielded values for the EC50 and EC10 (concentration that reduced first-feeding incidence by 50% and 10%, respectively). Note that the exposure to sub-optimal conditions continued during the 4-h feeding test. The response data are presented in figs. 11-15, 17-19, and table 8. 50% and 10% response values are presented in table 9.

2. In general, there was very little inter-specific difference in 24-h first-feeding EC50, despite the fact that larvae represented four orders (Gadiformes, Pleuronectiformes, Perciformes, and Scorpaeniformes) of teleost fish.

3. Based on 24-h LC50's, the perciform species were consistently less tolerant than the gadiform or the pleuronectiforms.

4. It cannot be claimed that the inhibition of first-feeding is the most sensitive indicator of environmental stress in marine fish larvae, nor were the experiments conducted here designed to test that hypothesis. The LC50/EC50 ratios supplied in table 9 demonstrate that it is a much more sensitive threshold than death, but the ratio varies from species to species and depends on the variable under consideration.

5. Larvae from small (yolk diameter less than about 1,25 mm), pelagic eggs were able to first-feed, at an optimal rate, over a time period of roughly 60 h (temperate species at 15°C) (figs. 6 & 7, table 2).

6. The two estuarine rotifers, Brachionus plicatilis and Proales cf. similis, proved to be excellent experimental foods. Pine (Pinus pinaster) pollen was found to be at least as attractive to first-feeding larvae as live rotifers, although it failed to support growth. The ciliates, Fabrea salina and Condyllostoma cf. patens, were very poor substitutes for rotifers.
7. Feeding containers of 350-ml capacity (fig. 4) were adequate for the ten species used as experimental animals. First-feeding incidence in these containers was maximal at a mean food density of five or more Brachionus per ml (Gaidropsarus), or ten or more Proales per ml (Diplodus). A standard density of 15 (10-20) rotifers per ml was used in tolerance testing.
8. First-feeding was inhibited by quite low levels of un-ionized ammonia (fig. 11, table 9). A negligible-effect concentration is thought to lie between 0,02 and 0,05 mg l⁻¹ NH₃-N (un-ionized). 24-h LC50 values fell within the range of published limits for the more sensitive freshwater juvenile and adult fish (salmonids).
9. Nitrite is virtually non-toxic to first-feeding marine fish larvae. 24-h LC50's ranged from 10³ to 10⁴ times those recorded for the most sensitive freshwater fish species (salmonids tested in water of very low dissolved solids), and first-feeding following a 24-h exposure was noticeably affected only at concentrations exceeding about 100 mg l⁻¹ NO₂-N (fig. 12).
10. Nitrate is likewise virtually non-toxic to these larvae. First-feeding was only beginning to be affected at concentrations in excess of about 200 mg l⁻¹ NO₃-N (fig. 13).
11. As long as carbon dioxide is near atmospheric equilibrium levels, a 24-h exposure to pH's as low as 6,0 does not appear to inhibit first-feeding. Drastic reduction in first-feeding incidence only occurred at pH's below 5,5 (fig. 14).

Table 9. Summary of tolerance limits. Ammonia is expressed in mg l⁻¹ NH₃-N (un-ionized), nitrite in mg l⁻¹ NO₂-N, nitrate in mg l⁻¹ NO₃-N, H⁺ and OH⁻ in pH units, oxygen in mg l⁻¹, and carbon dioxide in mg l⁻¹ CO₂-C. The LC50/EC50 ratios supplied for H⁺ and OH⁻ are based on hydrogen and hydroxyl ion activities, respectively, and not on units of pH. 95% confidence limits are in parentheses.

variable	species	24-h first- feeding EC50	24-h first- feeding EC10	24-h LC50	24-h EC10	LC50/EC50
NH ₃	<u>Gaidropsarus</u> <u>capensis</u>	0,11 (0,09-0,13)	0,07 (0,05-0,09)	0,46 (0,41-0,52)	0,43 (0,38-0,48)	4,1
	<u>Diplodus</u> <u>sargus</u>	0,10 (0,06-0,15)	0,03 (0,01-0,08)	0,36 (0,31-0,42)	0,29 (0,24-0,34)	3,8
	<u>Lithognathus</u> <u>mormyrus</u>	0,16 (0,11-0,22)	0,07 (0,04-0,10)	0,38 (0,33-0,42)	0,34 (0,29-0,38)	2,4
	<u>Pachymetopon</u> <u>blochi</u>	0,22 (0,17-0,28)	0,13 (0,10-0,16)	0,42 (0,36-0,48)	0,38 (0,31-0,46)	1,9
	Species 5 (Sparidae)	0,16 (0,11-0,23)	0,10 (0,07-0,15)	0,40 (0,34-0,47)	0,35 (0,28-0,42)	2,5
	<u>Gaidropsarus</u> <u>capensis</u>	450 (380-530)	280 (220-350)	2210 (1900-2560)	1500 (1210-1870)	4,9
	<u>Synaptura</u> <u>kleini</u>	350 (250-500)	180 (100-350)	2110 (1670-2670)	1210 (870-1690)	6,0
NO ₂ ⁻	<u>Heteromyceteris</u> <u>capensis</u>	340 (270-440)	190 (120-280)	2440 (2200-2690)	2170 (1900-2480)	7,1
	<u>Lithognathus</u> <u>mormyrus</u>	360 (260-480)	60 (20-190)	1230 (1020-1470)	670 (570-790)	3,5
	<u>Diplodus</u> <u>sargus</u>	330 (270-410)	150 (90-240)	1360 (1170-1590)	870 (770-990)	4,1
	<u>Gaidropsarus</u> <u>capensis</u>	1020 (770-1520)	360 (170-510)	>4000		4 ⁺
	<u>Heteromyceteris</u> <u>capensis</u>	710 (590-870)	420 (330-540)	5050 (3730-6850)	3510 (2820-4380)	7,1
	<u>Diplodus</u> <u>sargus</u>	780 (510-1200)	270 (150-480)	3560 (2920-4350)	3100 (2510-3820)	4,6
	<u>Lithognathus</u> <u>mormyrus</u>	600 (470-760)	270 (210-360)	3450 (3260-3660)	3020 (2800-3250)	5,8
NO ₃ ⁻	<u>Gaidropsarus</u> <u>capensis</u>					
	<u>Heteromyceteris</u> <u>capensis</u>					
	<u>Diplodus</u> <u>sargus</u>					
	<u>Lithognathus</u> <u>mormyrus</u>					
	<u>Gaidropsarus</u> <u>capensis</u>					
	<u>Heteromyceteris</u> <u>capensis</u>					
	<u>Diplodus</u> <u>sargus</u>					

Table 9. (continued)

variable	species	24-h first- feeding EC50	24-h first- feeding EC10	24-h LC50	24-h EC10	LC50/EC50
low pH	<u>Gaidropsarus</u> <u>capensis</u>	5,22 (4,84-5,61)	5,91 (5,54-6,27)	4,74 (4,52-4,97)	4,99 (4,77-5,21)	3,0
	<u>Heteromycteris</u> <u>capensis</u>	5,25 (4,97-5,53)	5,90 (5,52-6,29)	4,48 (4,31-4,65)	4,51 (4,33-4,69)	5,9
	<u>Diplodus</u> <u>sargus</u>	5,20 (4,93-5,47)	5,69 (5,42-5,96)	5,06 (4,84-5,27)	5,17 (4,94-5,39)	1,4
high pH	<u>Gaidropsarus</u> <u>capensis</u>	8,67 (8,56-8,77)	8,39 (8,25-8,53)	9,24 (9,12-9,36)	8,99 (8,87-9,10)	3,7
	<u>Heteromycteris</u> <u>capensis</u>	8,78 (8,64-8,92)	8,50 (8,29-8,71)	9,21 (9,06-9,35)	8,92 (8,79-9,06)	2,7
	<u>Diplodus</u> <u>sargus</u>	8,82 (8,69-8,95)	8,52 (8,34-8,70)	9,04 (8,84-9,14)	8,89 (8,78-9,00)	1,7
O ₂ (static)	<u>Pteromeris</u> <u>axillaris</u>	4,77 (4,06-5,48)	5,66 (4,43-6,89)	3,49 (2,99-3,99)	3,98 (3,35-4,61)	0,73
	<u>Pachymetopon</u> <u>blochi</u>	3,98 (3,24-4,71)	5,22 (4,12-6,31)	3,16 (2,67-3,66)	3,46 (2,89-4,02)	0,79
	Species 5 (Sparidae)			3,56 (2,92-4,20)	3,94 (3,15-4,73)	
O ₂ (flow- through)	<u>Trulla</u> <u>capensis</u>	4,30 (3,58-4,02)	5,41 (4,49-6,33)	<2,32		<0,54
	<u>Gaidropsarus</u> <u>capensis</u>	4,01 (3,26-4,76)	5,62 (4,56-6,67)	2,50 (1,78-3,23)	2,92 (2,25-3,60)	0,62
	<u>Congiopodus</u> <u>spinifer</u>	4,04 (2,90-5,19)	5,30 (4,15-6,45)	3,63 (2,98-4,27)	4,21 (3,48-4,94)	0,90
CO ₂	<u>Gaidropsarus</u> <u>capensis</u>	3,15 (2,43-3,86)	4,06 (3,15-4,97)	2,06 (1,58-2,55)	2,73 (2,08-3,38)	0,65
	<u>Heteromycteris</u> <u>capensis</u>	3,09 (2,26-3,93)	4,03 (2,29-5,08)	0,94 (0,55-1,32)	1,18 (0,80-1,57)	0,30
	<u>Heteromycteris</u> <u>capensis</u>	>7,7				

12. First-feeding begins to be inhibited following a 24-h exposure to elevated pH's of 8,4-8,5 (fig. 15). Given the modern propensity for green-water culture of fish larvae, one must consider high pH to be a potential stressor in the rearing tank.

13. For successful first-feeding of temperate marine species at 15°C, a dissolved oxygen concentration of at least 5,0-5,5 mg l⁻¹ should be maintained. This value is based on data collected on six species tested under static conditions (fig. 17). In flow-through experiments, a somewhat lower level of dissolved oxygen was tolerated (fig. 18). Considering known temperature effects on oxygen consumption rate and on tolerance to low dissolved oxygen (Doudoroff & Shumway, 1970), it is clear that higher concentrations of dissolved oxygen would be required for species being reared at temperatures approaching their thermal maxima.

14. Carbon dioxide is not likely to reach toxic levels in a rearing tank. No inhibition of first-feeding was recorded among sole (Heteromycteris capensis) larvae exposed for 24 h to a concentration of 7,70 mg l⁻¹ CO₂-C.

15. Larvae were less tolerant of reduced dissolved oxygen in the presence of a small amount (0,066 mg l⁻¹) of un-ionized ammonia than in its absence (fig. 19). The difference between the dissolved oxygen requirements in the two cases can probably be explained by addition of stressors, and does not require hypothesizing a respiratory pathway to account for ammonia-induced inhibition of first-feeding.

16. It is predicted that first-feeding inhibition arising from dissolved organics (bacterial and algal metabolites) would be a particularly fruitful area for further research.

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Part 2.

Common pelagic marine fish eggs
from the Cape of Good Hope:

Stages in the early
development of 40 species

ABSTRACT

Pelagic marine fish eggs were collected over a period of 28 months from inshore waters of the Cape of Good Hope. Some 40 species were encountered, of which about 30 were identifiable—either with the aid of published descriptions (particularly those of J.D.F. Gilchrist) or by rearing in the laboratory. Notes are included on the identification of eggs and larvae, duration of the incubation period, spawning season and distribution of the adult, and laboratory rearing. The text is accompanied by 184 figures of eggs, larvae, and juveniles.

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1. INTRODUCTION

The first in-depth studies of eggs and larvae of South African marine fishes were those undertaken by Prof. J.D.F. Gilchrist, who came to the Cape Colony from England in 1896. Originally as Cape Government Biologist and Honorary Curator at the South African Museum, later as Professor of Zoology at the South African College School (which became the University of Cape Town under his professorship) (Day, 1977), Gilchrist produced seven publications on the subject (Gilchrist 1903, 1904, 1914a, 1916, 1918, 1921; Gilchrist & Hunter, 1919). A total of 68 marine teleost species were dealt with in these articles. He described ripe ovarian eggs of 25 species, of which he successfully artificially fertilized 8; he described sea-spawned pelagic eggs of 31 species, of which he identified (correctly) 9. In addition, he dealt with the non-planktonic eggs of 10 species and with early viviparous stages of two more.

Since Gilchrist's death in 1926, there have been no local contributions to South African fish egg and larva biology on a comparable scale. Early life histories of several of the commercially important species have received attention, however, e.g. the South African pilchard, Sardinops ocellata (Davies, 1954; Louw & O'Toole, 1977), the Cape anchovy, Engraulis capensis (King et al., 1978); the hakes, Merluccius spp. (Matthews & De Jager, 1951; Haigh, 1972a), the maasbanker, Trachurus capensis (Haigh, 1972b; King et al., 1977), and the snoek, Thrysites atun (De Jager, 1955; Haigh, 1972a).

The present author's studies on water quality requirements for first-feeding (Part 1 of this thesis) necessitated the collection and identification of pelagic fish eggs from the inshore plankton of the Cape of Good Hope. Although many of the eggs encountered during those studies have already been quite adequately described by Gilchrist, enough new material was made available to warrant a review of the subject. Whenever possible in the treatment which follows, reference is

made to Gilchrist's original descriptions.

Several limitations have been placed, intentionally or unintentionally, on the scope of this project: (1) Only species with planktonic eggs have been included. (2) All material (with one exception) was collected in the egg stage by plankton net and maintained in the laboratory until the desired developmental stage had been reached. (3) No descriptions were based on ripe ovarian eggs or on artificially fertilized eggs or larvae, as these could not be obtained. (4) All drawings were based (with two exceptions) on live, anaesthetized specimens.

Although most of the egg and larval stages described bear coloured pigment in addition to melanophores, only the latter are shown in the drawings presented in this thesis. Provision has been made to incorporate the coloured pigmentation in the version to be published. The author apologises for any reference in the text to colours that do not appear in the figures.

2. MATERIALS AND METHODS

Collecting sites, four on the Atlantic side of the Cape Peninsula, three on the False Bay side, are indicated on the accompanying map (fig. 1). An introduction to the biotic and abiotic features of the region may be obtained by consulting the reviews by Brown & Jarman (1978) and Heydorn (1978). Movements of surface water in the Cape Peninsula area defy generalization—this is apparent from the drift-card data presented by Duncan & Nell (1969).

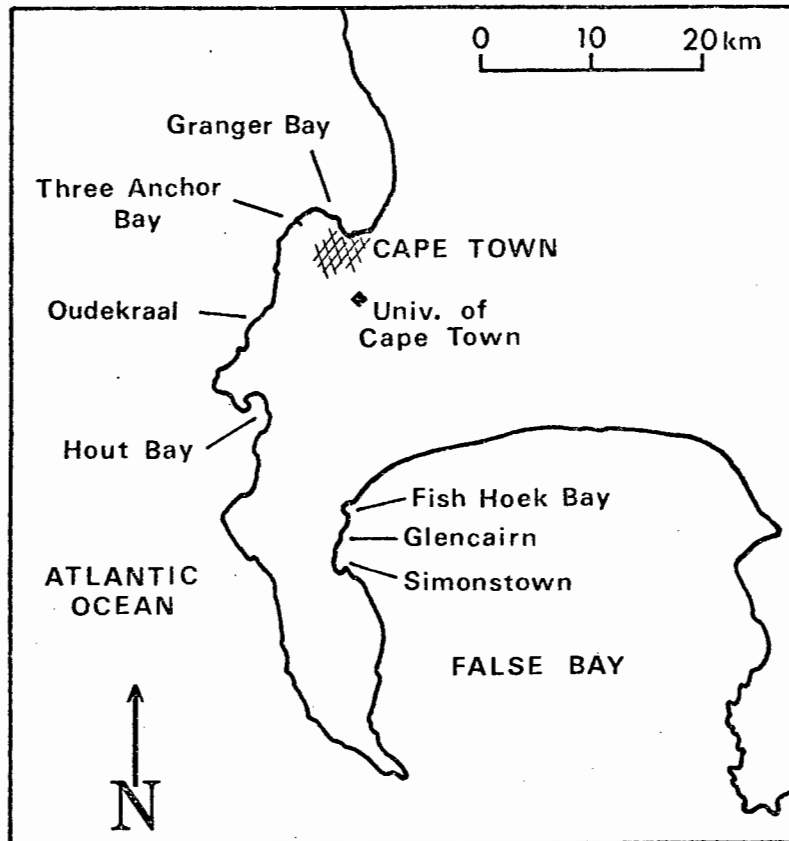


Figure 1. The Cape of Good Hope.

Rearings were conducted in eight, rectangular, all-glass, 10-l tanks connected to a small closed-circulation system. The system incorporates a 500-l reserve tank and a 40-l submerged biofilter, and is powered by air-lift. Half the sea water in the system was replaced at approximately 12-month intervals. Several simple rearing tank designs

were experimented with. The most successful is based on the well-known (see Spotte, 1970) "false-bottom" or "sub-sand filter" arrangement. The tank has a perforated filter plate raised a centimetre off the bottom. A 1-cm bed of coarse beach sand (1,5-2,5 mm particle size) covers the filter plate; a thin (0,5 cm) layer of crushed (100-700 μ m particle size) coal or bone charcoal covers the beach sand. The back and side walls of the tanks are covered externally by black polyethylene sheet, which with the black-sand bottom, provides a background against which larvae can presumably better perceive their prey. When the tank is emptied for cleaning, the two layers can be rapidly separated with a 1-mm sieve. Water from a small header tank enters at a rate just sufficient to result in a 90% replacement every 24 h (i.e. ca. 15 ml min⁻¹). Water exits from beneath the filter plate by constant-level siphon. A fine jet of compressed air directed obliquely at the surface of each rearing tank keeps the contents sufficiently mixed without recourse to bubbling or mechanical mixing. Fluorescent lighting directly over the tanks produces about 2500 lux at the water surface on a 14L:10D cycle. During the 10 h of darkness, there is low-level lighting from other sources in the room. Almost all rearings were carried out at 15°C.

Very small-mouthed larvae were offered Proales cf. similis at first-feeding; larger-mouthed larvae were given Brachionus plicatilis. Later, copepods (Tisbe sp. and Pseudodiaptomus hessel), ostracods ("Cypridopsis" sensu lato sp.), and amphipods (Austrochiltonia subtenuis) were offered. Suspensions of phytoplankton (Chlorella or Phaeodactylum) were added daily, along with the food. Additional rearing notes accompany species descriptions.

When possible, drawings were made at the following ages (post-hatch): egg, newly-hatched (0-6 h), 2 d, 4 d, 8 d, 16 d, and 32 d. They were done with the aid of a camera lucida from living (with two exceptions: figs. 93, 105) eggs and larvae, anaesthetized with MS-222. The fish drawn

were subsequently fixed (3-5% formalin) for later reference. The specimens will be deposited in the collection of the South African Museum, Cape Town. It must be stressed that series of drawings of a particular species do not represent subsequent stages of the same individual.

Notochord length (NL) was measured from the snout (not mandible) tip to the posterior end of the notochord; standard length (SL), from the snout tip to the posterior end of the hypural; total length (TL), from the most anterior point (either snout or mandible (but with mouth closed), sometimes yolk sac) to the most posterior. Myomeres were counted in the following way: 1) Any myomere intersected by a vertical line passing through the centre of the anus was considered a pre-anal myomere. 2) The areas anterior to the first myoseptum, and posterior to the last myoseptum, were both counted as myomeres. 3) The expression "myomeres: 10 + 15 = 25" would refer to the presence of 10 pre-anal and 15 post-anal myomeres counted in the manner just described. All ages refer to the post-hatching interval (not post-fertilization). Because of the shrinkage of larval fish, both at death and in the fixative (Blaxter, 1971; Rosenthal et al., 1978), measurements are accompanied by the expressions, "alive" or "fixed". Taxonomic nomenclature follows that of Smith (1975).

3. COLLECTION RECORDS

The results of 58 collection outings over a period of 28 months are assembled in table 1. Several comments must be made regarding these data.

Those species that were readily identifiable in the egg stage could be counted during the original sorting operation. Those that were only recognizable in the early larva stage could only be enumerated after hatching. Others were only counted at first-feeding, and two species (Gymnocrotaphus curvidens and Chrysoblephus laticeps) were only recognized towards metamorphosis. The values listed in the table correspond to the number of eggs or larvae alive at the earliest stage at which it was feasible to enumerate them. It is clear that any mortalities incurred prior to counting would induce an underestimation of abundance. The consequences of this procedure are not as serious as they might seem. With the exception of the two species mentioned, all counts were made at or prior to first-feeding. Since mortality to this stage was customarily less than 50%, the values given in the table may be taken as reasonable approximations of the number of eggs taken in the collections. The same may not be said for G. curvidens and C. laticeps.

The values given refer to the total number (counted as explained above) of eggs taken during that month, regardless of how many collections were involved. The number of collections making up any month's data is also given. It may be calculated that egg density ranged from 0,00 eggs m^{-3} to about 3 eggs m^{-3} , with an overall mean of roughly 0,5. Further manipulation of these data is probably not warranted. There was tremendous variation in species composition and numbers from collection to collection—even between collections made at the same site on consecutive days. The pooling of 28 months' data has had the effect of dampening this variation.

The temperatures provided in table 1 are the monthly means of daily readings averaged over the years 1976-1978 (by courtesy of the Maritime Weather Office, Silvermine, Cape).

4. DESCRIPTIONS OF EGGS AND LARVAE

4.1 CLUPEIDAE

Three clupeid species are found in Cape of Good Hope waters: Etrumeus teres, Sardinops ocellata, and Gilchristella aestuarius (Smith, 1965; Day et al., 1970). Eggs of the red-eye round herring and South African pilchard are well known (see below for references). Eggs of Gilchristella have not been described, although Gilchrist (1914a) netted a pelagic clupeid egg in Knysna Lagoon (his Species XXII) that is probably referable to this species. The egg was small, 0,71-0,72 mm in diameter; perivitelline space relatively wide, 0,08 mm; without oil globule; yolk with slight traces of vesiculation. Yolk-sac larvae (age unspecified) had a posterior rectum and measured 1,5-1,8 mm total length, of which 37% was occupied by yolk. Melville-Smith (1978) reported that Gilchristella eggs were pelagic, and were probably spawned in the upper reaches of estuaries (specifically, the Swartkops Estuary, Port Elizabeth). He did not describe the eggs. There is evidence that successful spawning and development can occur in salinities ranging from 0 to at least 47‰ (Wallace, 1975a).

4.1.1 Etrumeus teres (red-eye round herring)Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Species VIII): egg, p. 199; larva, p. 199, fig. 32.

Gilchrist, 1916 (as Species VIII): egg, p. 21; larva, p. 21, fig. 17.

Gilchrist & Hunter, 1919 (as Species VIII (Clupea sp.?)): egg, p. 10; larva, p. 10.

O'Toole & King, 1974: egg, p. 445, fig. 2; larva, p. 447, figs. 3-5.

(Additional references are cited by O'Toole & King, (1974).)

Egg.

Table 3. The combination of coarse yolk segmentation, lack of an oil globule, and size effectively distinguishes the egg of this species from any others encountered during

this study. Note, however, that the newly-spawned egg of the lace sole, Synaptura kleini, which appears (falsely) to lack oil globules, has a size distribution which broadly overlaps that of E. teres. The yolk vesiculation of E. teres serves to separate them at this stage.

Larva.

Table 3. Uchida (1958, pl. 5-6) illustrated the entire developmental series. Feeding larval stages have much larger mouths than either the Cape anchovy or the South African pilchard of the same length. Once dorsal and anal fins appear, E. teres may be distinguished from the latter two species by the relative positions of these fins: there are 3-4 "postdorsal-preanal myomeres" (full myomeres between the posterior of the dorsal fin base and anterior of the anal fin base) (Houde & Fore, 1973) in E. teres, and usually 5-7 such myomeres in Sardinops ocellata (fig. 3). The two fins overlap in the case of the Cape anchovy (fig. 5).

Meristics.

D 16-19, A 9-11 (Smith, 1965). Vertebrae: 48-56 (Whitehead, 1963).

Geographic and seasonal distribution:

Whitehead (1963) recognized "probably seven discrete populations" of this species worldwide. The southern African population occurs from (at least) Walvis Bay to Beira (Day et al., 1970). Eggs were taken intermittently all year on both sides of the Cape Peninsula. Geldenhuys (1978) found that small red-eye were recruited to the fishery throughout the year and deduced year-round spawning.

Bearing notes.

Incubation time (15°C) was estimated (fig. 185.1) at 70 ± 10 h, which agrees very closely with the value (about 68 h) provided by O'Toole & King (1974, fig. 6). First-feeding was generally successful on Brachionus, and a few larvae reached an age of 30 days. None survived to metamorphosis.

4.1.2 Sardinops ocellata (South African pilchard) Figs. 2-3.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Species III): egg, p. 196, figs. 23-24; larva, p. 196, fig. 25.

Gilchrist, 1916 (as Clupea sagax): egg, p. 20, fig. 16; larva, p. 20, fig. 16.

Hart & Marshall, 1951 (as Sardinops sagax): egg, fig. 1a; larva, figs. 1b-1c.

Davies, 1954: egg, p. 10, pl. 5, figs. 1-3; larva, p. 11, pl. 6, figs. 1-4.

Louw & O'Toole, 1977: larva, p. 129, figs. 2-5.

King, 1977a: egg, p. 12, fig. 6; larva, p. 26, fig. 9.

Egg.

Table 3. The wide perivitelline space, single (usually) oil globule, and size sets this egg apart from any of the others encountered.

Larva.

Figs. 2-3, table 3. Larval stages of this commercially important species have been well described (see, in particular, Louw & O'Toole, 1977).

Meristics.

D 18-20, A 18-20, P 18 (Louw & O'Toole, 1977). Baird (1971) gave a mean vertebral count of 49,4 for a sample of S. ocellata from the Cape Province, 49,2 for a sample from Natal (not significantly different).

Geographical and seasonal distribution.

S. ocellata ranges from about Cape Frio (18°30'S) in the Atlantic off Namibia (King, 1977b) to Richards Bay (Day et al., 1970). Davies (1956) encountered pilchard eggs in the plankton throughout the year, but concluded that major spawning only occurred from September to February, inclusive. He detected two peaks during this period: September and February. Off Namibia, spawning begins in June or July and extends until April, with two peaks: a main peak in August-September, a lesser peak in February-March (Matthews, 1964).

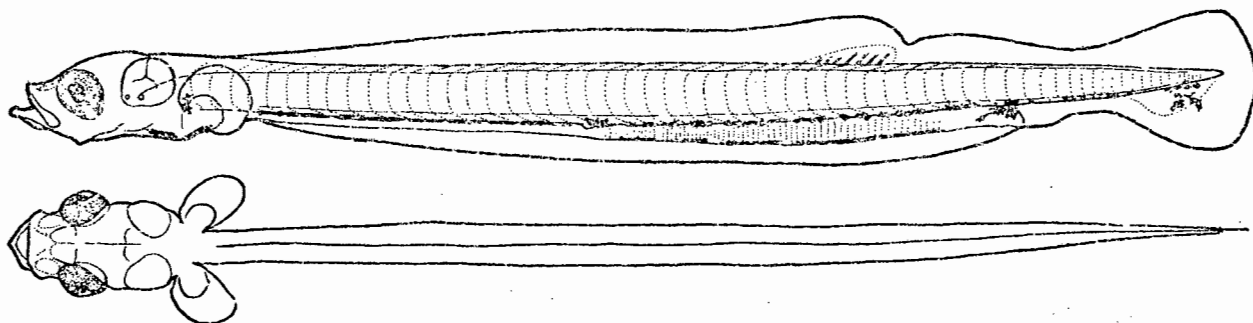


Figure 2. *Sardinops ocellata* at 16 days (17-19°C), lateral and dorsal views. NL (alive) = 10,1 mm, NL (fixed) = 9,3 mm. Myomeres: 41 + ca. 15.

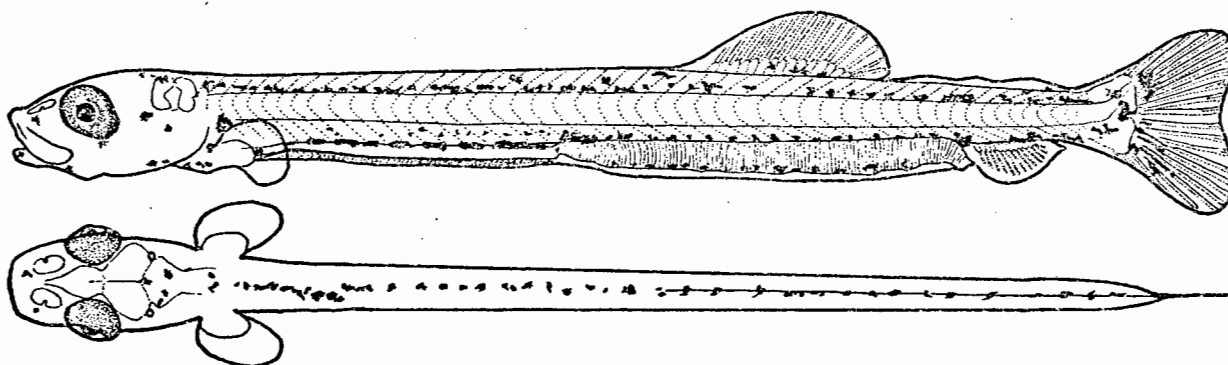


Figure 3. *Sardinops ocellata* at 32 days (17-19°C), lateral and dorsal views. SL (alive) = 16,7 mm, SL (fixed) = 14,7 mm. Myomeres: 41 + 9 = 50.

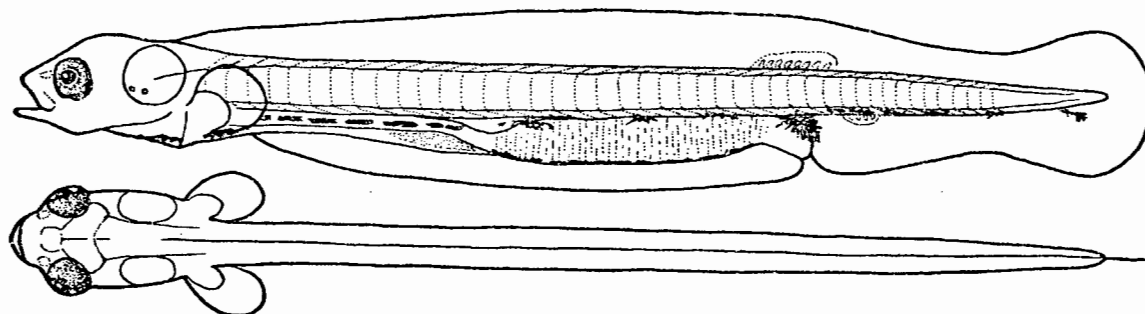


Figure 4. *Engraulis capensis* at 16 days (17-19°C), lateral and dorsal views. NL (alive) = 6,3 mm, NL (fixed) = 5,9 mm. Myomeres: 30 + ca. 15.

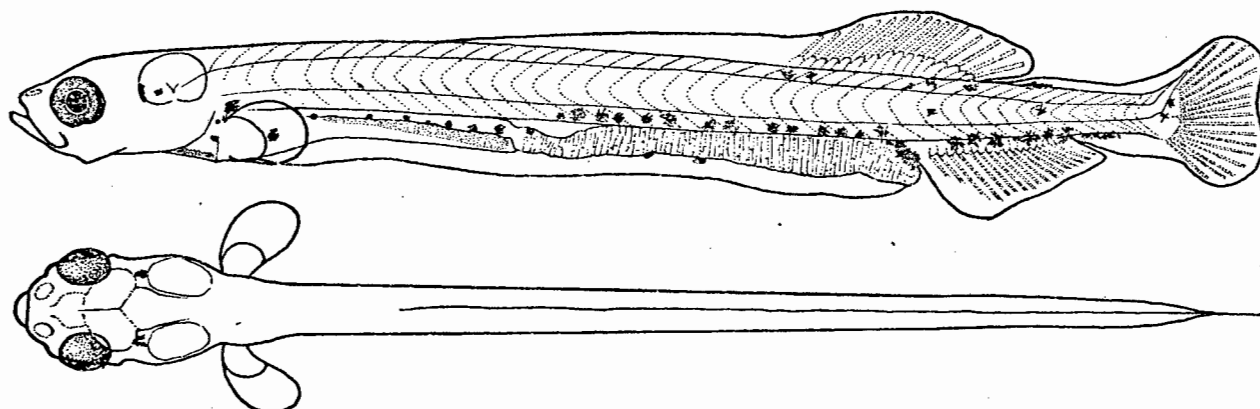


Figure 5. *Engraulis capensis* at 32 days (17-19°C), lateral and dorsal views. SL (alive) = 10,4 mm, SL (fixed) = 8,9 mm. Myomeres: 30 + 14 = 44.

King (1977b) reported regional differences in spawning activity off Namibia. Pilchard eggs are rare in the inshore plankton of the Cape Peninsula (table 1).

Bearing notes.

A batch incubated at 15°C demonstrated excellent hatchability (>90%) but survival through the yolk-sac stage was very poor (<10%). A subsequent batch incubated and maintained at 17-19°C yielded a much higher rate of survival to first-feeding. The difference may have been due to factors other than temperature: King (1977a) reported a lower thermal limit of 11°C for S. ocellata eggs, and 13°C for yolk-sac larvae through the eyed stage. Davis (1956) set 13°C as the lower threshold for major spawning, although eggs have been collected in waters of 11°C (Stander, 1963).

A few larvae survived to 45 days post-hatch, feeding first on Proales, later on Brachionus and Tisbe. None reached metamorphosis.

4.2 ENGRAULIDAE

The family is represented in Cape Peninsula waters by a single species.

4.2.1 Engraulis capensis (Cape anchovy) Figs. 4-5.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1916: egg, p. 22.

Gilchrist & Hunter, 1919: egg, p. 9, fig. 21; larva, p. 9, fig. 22.

King et al., 1978: egg, p. 38, fig. 2; larva, p. 40, fig. 4.

Egg.

Table 3. No other teleost egg known from Cape Peninsula waters is as markedly elliptical as this. All the other elliptical eggs encountered during this study have oil globules.

Larva.

Figs. 4-5, table 3. Refer to the above-cited publications for descriptions of early larvae. Older larvae are easily distinguished from clupeid larvae by the shorter gut and relative positions of the dorsal and anal fins. (figs. 4-5).

Meristics.

D 14-16, A 18-20. (Smith, 1965).

Geographic and seasonal distribution.

E. capensis eggs have been taken in the E. Atlantic as far north as 18°30'S off Namibia (King, 1977b). Anders (1975) reported anchovy eggs (but these may not have been E. capensis) in the W. Indian Ocean as far north as 28°S off KwaZulu. Day et al. (1970) reported St. Lucia as the northern range limit of the adult in the Indian Ocean. In the present study, anchovy eggs were collected October to February, inclusive, in False Bay; a few were taken in March off Three Anchor Bay (table 1). The False Bay records are in accord with the known spawning season of this species: October to February, with a peak in November-December (Stander & Roux, 1968).

Bearing notes.

Almost all the eggs hatched within 48 h of collection, one hatched between the 60th and 72nd hour. (fig. 185.2). King et al. (1978) obtained an incubation time (blastodermal cap stage to hatching) of 66 h at 15°C.

Bearing was attempted at 17-19°C. First-feeding was successful on Proales; feeding incidence was very low when only Brachionus was offered. None of the larvae survived to metamorphosis; the last individual died at 53 days post-hatch.

4.3 STERNOPTYCHIDAE

4.3.1 Maurolicus muelleri (Müller's pearlsides)

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904 (as Species XVI): egg, p. 139, figs. 39-40.

Sanzo, 1931a (as Maurollicus pennanti): egg, p. 56, pl. 5; larva, p. 57, pl. 5.

Robertson, 1976: egg, p. 313, fig. 1a; larva, figs. 1-2.

(Additional references are cited by Sanzo (1931) and Robertson (1976).)

Egg.

Table 3. The unusual egg, characterized by a very thick, transparent chorion produced externally in concave, hexagonal facets, is immediately recognizable. The total diameter of the egg, with envelope, varied from 1,80 to 2,10 mm in the few examples encountered during the present study. Yolk diameter was more constant: 1,03-1,12 mm; oil globule: 0,25-0,26 mm.

Larva.

Table 3. The larva is without pigment at hatching. Refer to the above-cited publications for further description.

Meristics.

D 9-12, A 23-27 (Smith, 1965).

Geographic and seasonal distribution.

Cosmopolitan, mesopelagic species; its range includes the whole of southern Africa. Based on published data (reviewed by Robertson (1976), the period of spawning is of long duration. A maximum seems to occur in spring and summer.

Bearing notes.

No larvae survived to first-feeding.

4.4 SCOMBERESOCIDAE

4.4.1 Scomberesox saurus (saury)

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904: egg, p. 145, fig. 53; larva, p. 145, figs. 54-56.

Gilchrist, 1916: egg, p. 19; larva, p. 20.

D'Ancona, 1931: egg, p. 161; larva, p. 161, pl. 8-9.

Nesterov & Shiganova, 1976: egg, p. 279, fig. 3; larva, p. 280, fig. 4.

(Additional references are cited by Nesterov & Shiganova (1976).)

Egg.

Table 3. Gilchrist (1904) described in detail the egg and early larva of S. saurus. It is readily distinguished from other eggs known from the Cape Peninsula by the combination of size, narrow perivitelline space, and absence of an oil globule.

Larva.

Table 3. The larva at hatching is blue dorsally, silver ventrally. One of Gilchrist's (1904) was 8,5 mm TL. His figures illustrate very well the appearance of early larvae; those of D'Ancona (1931), the more advanced stages.

Meristics.

D 9-11 + 5-6, A 12-13 + 6-7 (Smith, 1965).

Geographic and seasonal distribution.

This saury inhabits subtropical and warm temperate waters of the Southern Hemisphere and the N. Atlantic and Mediterranean (Parin, 1973). Day et al. (1970) reported it to be common in False Bay. The seeming rarity of the eggs in the plankton at Fish Hoek (table 1) suggests that it does not ordinarily spawn in False Bay. The very early state of development of the three eggs taken in this study indicates, however, that they may have been spawned there. Date of capture was 3 February. Gilchrist's material was netted June-September, some 30-40 miles off the Cape of Good Hope. Spawning by this species in the N. Atlantic occurs all year in water of 16,8-23,7°C (Nesterov & Shiganova, 1976).

Rearing notes.

The three available eggs were incubated at ca. 18°C.

Two hatched; both hatchlings died within two days. They swam unceasingly at the surface of the 10-1 tank; no obvious feeding manoeuvres were observed.

4.5 GADIDAE

Only three gadid species are recognized from shelf waters of the Cape Province: Gaidropsarus capensis, G. insularum, and Physiculus capensis. Penrith (1967) reviewed the nomenclature of the two Gaidropsarus species and provided several characters by which they could be distinguished. Collection records of the eight specimens that were available to him (Penrith, pers. comm., 1978) were insufficient to permit delineation of the ranges for the two species, but implied that G. insularum (type locality: Tristan da Cunha) was the rockling of the western Cape Province and G. capensis (type locality unknown), the rockling of the eastern Cape Province. Only G. insularum was listed among the False Bay fauna by Penrith in Day et al. (1970).

Gaidropsarus eggs are abundant in the plankton on both sides of the Cape Peninsula throughout the year, and were successfully reared through metamorphosis on many occasions. All the specimens examined (n=18; SL=2,0-10,1 cm) from both sides of the Cape Peninsula are referable to G. capensis rather than G. insularum: D1 50-58 (and one with 67), D2 45-52, A 37-43, P 18-21, ratio of D1 base to head length: 0,12-0,14 (A single specimen, SL=7,3 mm, yielded a ratio of 0,09, but the fin-ray counts, eye/head ratio, and caudal peduncle/head ratio did not differ from that of other specimens of similar size.)

4.5.1 Gaidropsarus capensis (Cape rockling) Figs. 6-11.

Previous descriptions of eggs and/or larvae.

Gilchrist & Hunter, 1919 (as Onos capensis): egg, p. 7, fig. 14; larva, p. 7, figs. 15-17.

Figure 6. *Gaidropsarus capensis* egg.
0,75 mm in diameter, oil globule
0,16 mm.

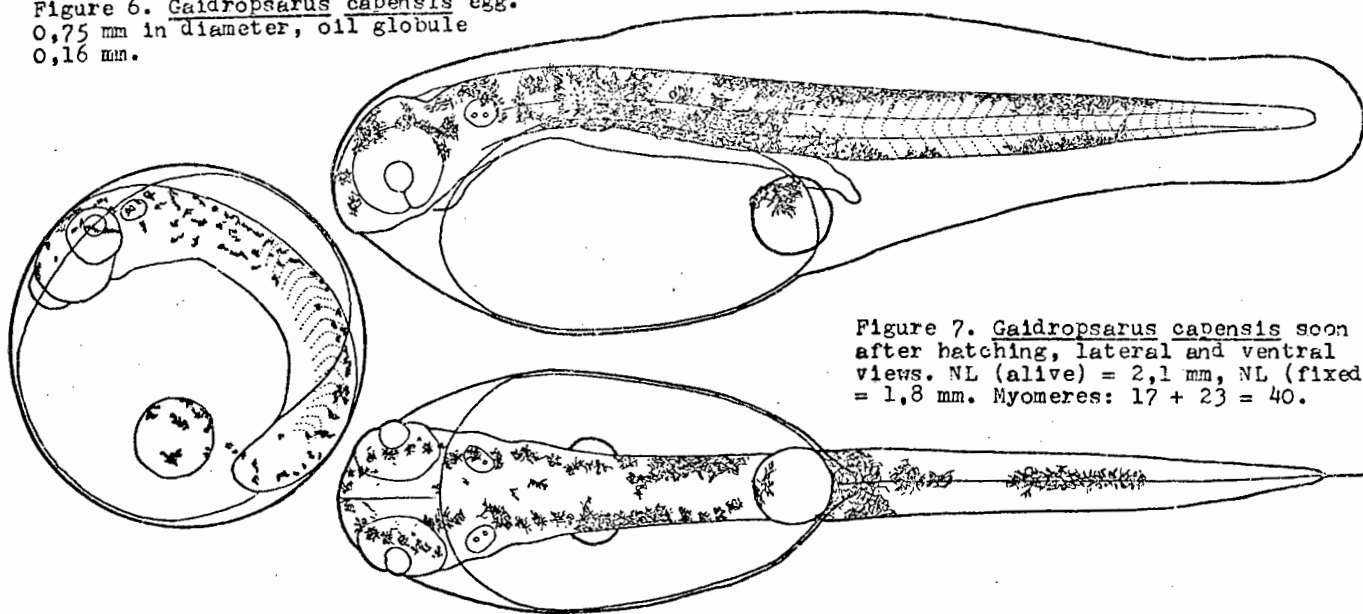


Figure 7. *Gaidropsarus capensis* soon after hatching, lateral and ventral views. NL (alive) = 2,1 mm, NL (fixed) = 1,8 mm. Myomeres: 17 + 23 = 40.

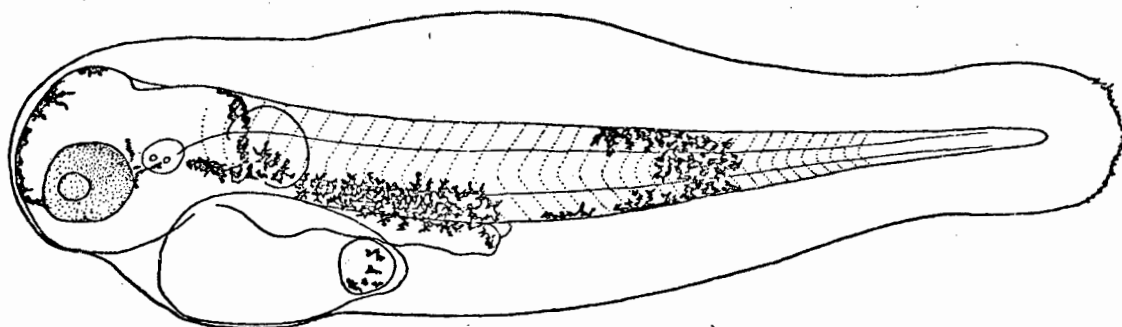


Figure 8. *Gaidropsarus capensis* at 2 days (15°C). NL (alive) = 2,3 mm, NL (fixed) = 2,1 mm. Myomeres: 15 + 23 = 38.

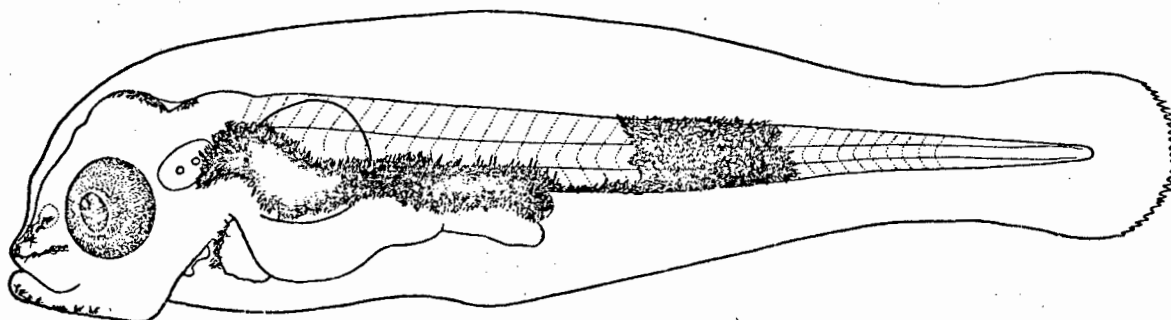
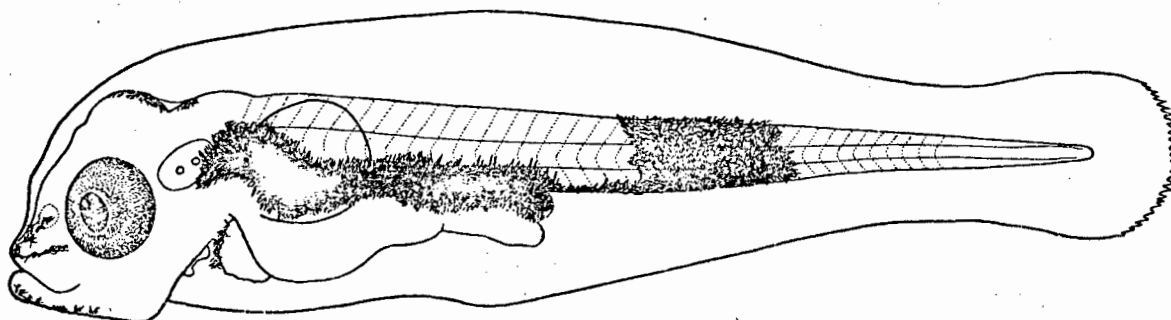


Figure 9. *Gaidropsarus capensis* at 4 days (15°C). NL (alive) = 2,6 mm, NL (fixed) = 2,2 mm. Myomeres: 15 + 23 = 38.



Egg.

Fig. 6, table 3. Eggs in the earliest stages have up to 5 oil globules in a single clump. These consolidate into one (occasionally more) by the time the egg hatches. After consolidation, the globule measures 0,16-0,18 mm. In advanced embryos the globule bears several (about 3-6) melanophores and is normally (see rearing notes, below) fixed in the posterior end of the yolk sac. The chorion is non-wetting, and breaches the surface when placed in a calm vessel of clean sea water.

Larva.

Figs. 7-11, table 3. The larva at hatching bears black pigment only. Particularly noticeable is the concentration of melanophores on the tail, about half-way between the yolk sac and the caudal extremity. The ventral fins develop early (about 12 days post-hatch, 15°C), becoming very prominent after about 3 weeks. The first appearance of colour is in these fins, in the form of deep red streaks in the interradians (fig. 10). The irridescent blue of older G. capensis larvae is gradually replaced by brown at about 2,1-2,5 cm TL, when the free-swimming, pelagic larva moves to the bottom and takes up a secretive life-style under stones. At 15°C, this transition to the benthos takes place at an age of about 2 months.

Meristics.

D1 50-58, D2 45-52, A 37-43, P 18-21, Vertebrae: 44-45. (this study).

Geographic and seasonal distribution.

The distributions of the two nominal South African Gaidropsarus species are uncertain at present. Day et al. (1970) reported rocklings in the E. Atlantic as far north as Lamberts Bay; Smith (1965) reported rocklings in the W. Indian Ocean as far east as Algoa Bay. Like Gilchrist & Hunter (1919), the present author took rockling eggs all year (table 1).

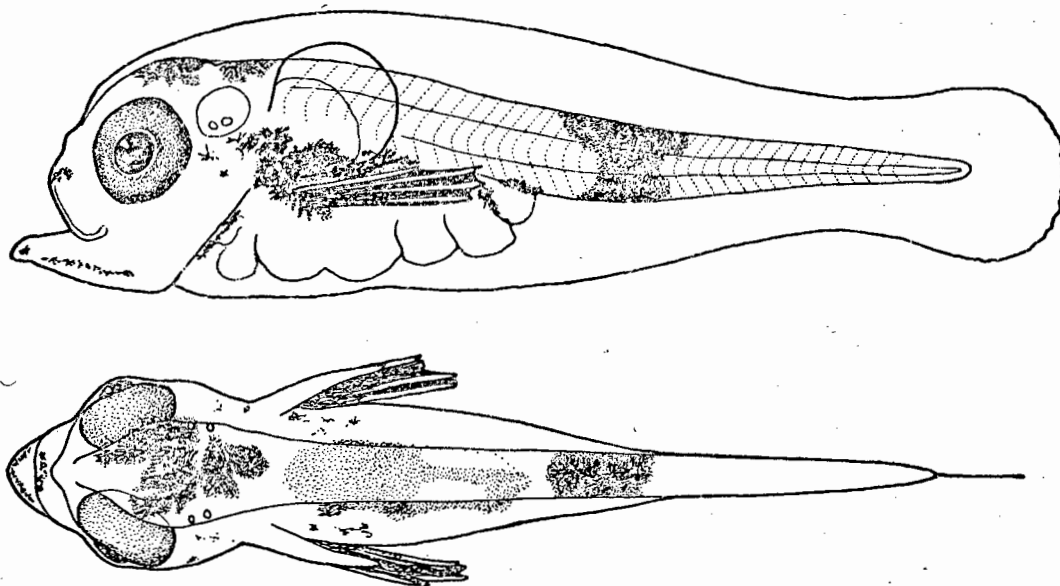


Figure 10. *Gaidropsarus capensis* at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,1 mm, NL (fixed) = 2,8 mm. Myomeres: 13 + 25 = 38.

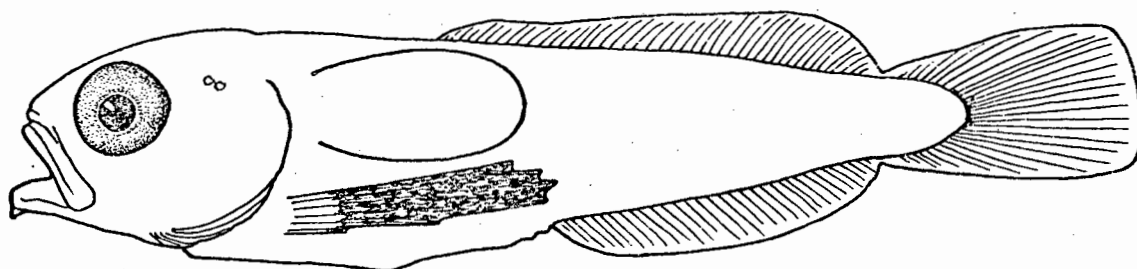


Figure 11. *Gaidropsarus capensis* at 55 days (15°C). SL (alive) = 12,8 mm, SL (fixed) = 12,1 mm. Fin elements have not yet reached definitive counts. D1 0, D2 44, A 34.

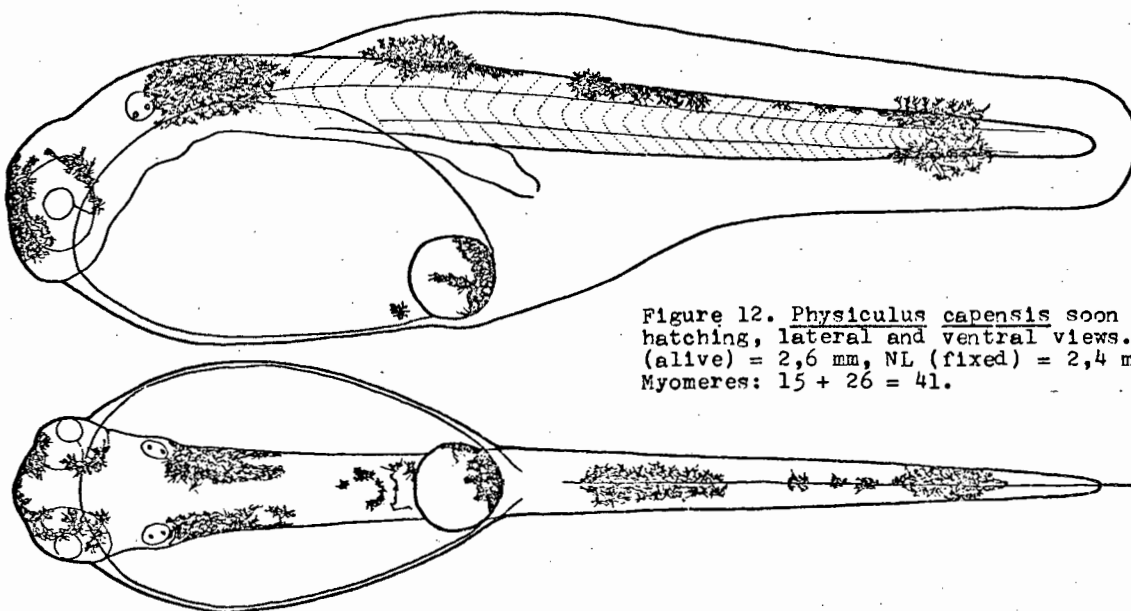


Figure 12. *Physiculus capensis* soon after hatching, lateral and ventral views. NL (alive) = 2,6 mm, NL (fixed) = 2,4 mm. Myomeres: 15 + 26 = 41.

Rearing notes.

Incubation time (15°C): 96 ± 10 h (fig. 185.3). Age-at-optimal-first-feeding (defined in Part 1 of this thesis) is 145 h post-hatch. At least 50% of larvae are capable of first-feeding on Brachionus between the age of 100 and 190 h post-hatch. Proales was also taken by first-feeding larvae.

Five to ten percent of the rockling eggs collected produced a hatchling with the oil globule freely mobile in the yolk, i.e., unattached to the yolk membrane. Towards the end of yolk absorption (4-5 days post-hatch, at 15°C), these larvae develop a white area (characteristic of necrotic tissue) around the globule, and the latter is not absorbed. Although the larvae so effected were usually as active as normal larvae, they were unable to feed.

4.5.2 Physiculus capensis (bigeye rockling) Figs. 12-15.

Previous descriptions of eggs and/or larvae.

?Gilchrist & Hunter, 1919 (as "Species ?"): egg, p. 13; larva, p. 13.

The eggs described by Gilchrist & Hunter (1919) from Table Bay (December) more closely resemble the eggs of Physiculus capensis than any of the other eggs encountered in this study. Their eggs were slightly smaller, however (0,82-0,89 mm, oil globule 0,16-0,18 mm), and the larvae at hatching were shorter (ca. 2,1 mm TL, as opposed to ca. 2,7 mm).

Notes on identification.

The identification of this material as P. capensis is based on the similarity of the early larva to that of P. dalwigki, from the N.E. Atlantic and Mediterranean (see De Gaetani, 1928, figs 2-3 or D'Ancona, 1933, figs. 206-207).

Egg.

Table 3. The dimensions of the egg and oil globule fall within the range of several common perciform species. As hatching nears, the egg may be identified by characteristics of the embryo (see larval characters below). There are no xanthophores, only diffuse patches of brown pigment.

Larva.

Figs. 12-15, table 3. Gadid features are already present at hatching: the lateral position of the anus, the relatively high myomere count (40-45). The yolk sac is pear-shaped at hatching, with the oil globule fixed in the narrow, posterior end. At first-feeding there is a very marked downward flexure of the notochord at the level of the nape. Ventral fins appear early (by the 8th day at 15°C), and if development parallels that of P. dalwigki, they attain considerable size in later larval stages. A 30-mm specimen of P. capensis examined by Barnard (1925-1927) already had the basic features of an adult.

Meristics.

The two South African Physiculus species differ in fin-ray counts and vertebral number. P. capensis: D 10 + 53-55, A 60-62, Vertebrae: 51. P. natalensis: D 8-9 + 62-64, A 65-70, Vertebrae: 54 (Winterbottom, 1974).

Geographic and seasonal distribution.

Cape Peninsula to East London (Smith, 1965). Eggs were taken in small numbers in April, July, and September through November, inclusive, on the Atlantic side of the Peninsula; none was found in collections from False Bay.

Bearing notes.

Bearing attempts were unsuccessful. A few larvae first-fed on Brachionus at 160-200 h post-hatch, but the majority were extremely sluggish and failed to feed at all. None survived beyond two weeks of age. De Gaetani (1928) kept P. dalwigki alive for 15 days after hatching; Mancuso (1926) maintained a 20-mm, sea-caught larva through metamorphosis.

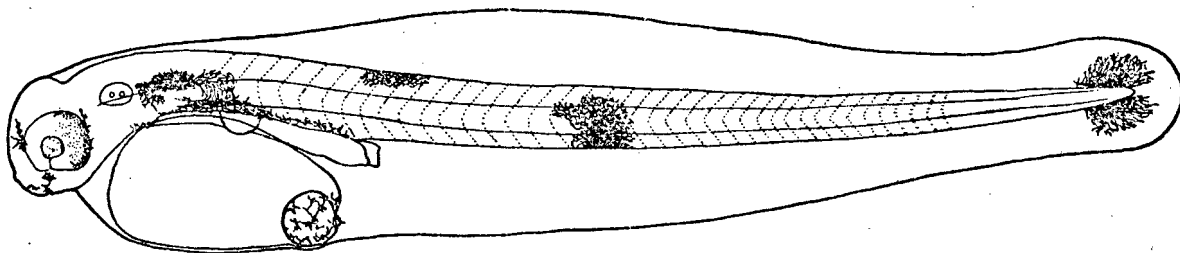


Figure 13. *Physiculus capensis* at 2 days (15°C). NL (alive) = 3,5 mm, NL (fixed) = 3,3 mm. Myomeres: 11 + 32 = 43.

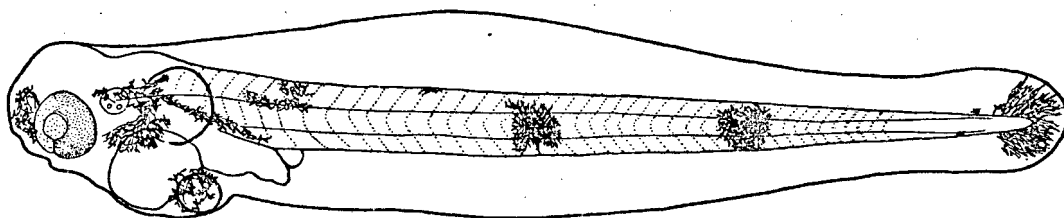


Figure 14. *Physiculus capensis* at 4 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,2 mm. Myomeres: 16 + 37 = 43.

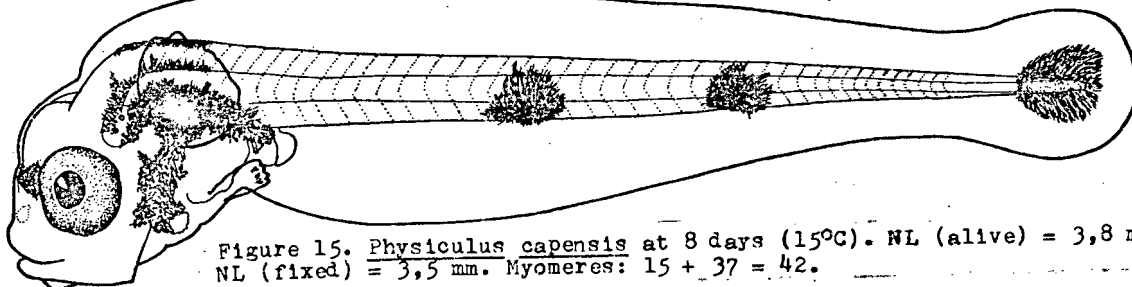


Figure 15. *Physiculus capensis* at 8 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,5 mm. Myomeres: 15 + 37 = 42.

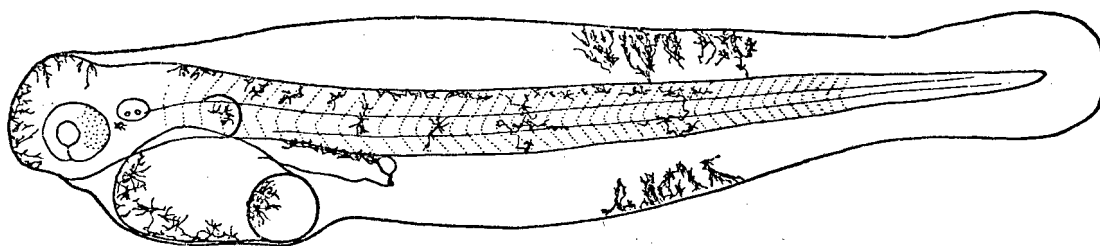


Figure 16. *Merluccius capensis* at 2 days (15°C). NL (alive) = 3,5 mm, NL (fixed) = 3,2 mm. Myomeres: 13 + 32 = 45.

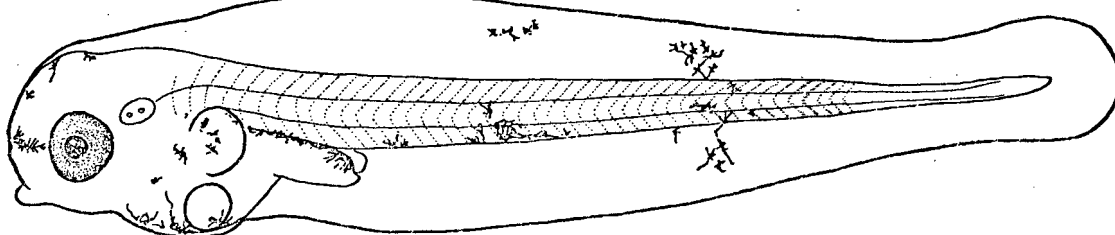


Figure 17. *Merluccius capensis* at 4 days (15°C). NL (alive) = 3,6 mm, NL (fixed) = 3,3 mm. Myomeres: 12 + 33 = 45.

4.6 MERLUCCIIDAE

All published descriptions of early stages of hakes from southern Africa have been attributed to the shallow-water hake, Merluccius capensis, although two other hake species are known to inhabit these waters (M. paradoxus and Macronurus capensis). It is only relatively recently that there has been any attempt to distinguish the adults of these species, not to mention eggs and larvae. The present author has little hesitation in claiming that the material collected in this study is referable to M. capensis. The eggs were netted within 3 km of shore. M. paradoxus is restricted to deeper water, and only juveniles are taken at depths of less than about 300 m (Botha, 1973). Macronurus capensis has not been taken by research vessels of the Sea Fisheries Branch in extensive trawling surveys off the western Cape Province (Andrew Payne, Sea Fisheries Branch, Cape Town, pers. comm., 1979).

4.6.1 Merluccius capensis (shallow-water hake) Figs. 16-18.Previous descriptions of eggs and/or larvae.

(Some of the following references may pertain to hakes other than M. capensis. The vertebral counts cited by Haigh (1972a, table 1), for example, fall into the known range of M. paradoxus rather than M. capensis.)

Gilchrist, 1916: egg, p. 14.

not Gilchrist & Hunter, 1919 (The eggs and larvae they identified as M. capensis are described in the present work as "Species 8".)

Hart & Marshall, 1951: larva, fig. 1d.

Matthews & De Jager, 1951: egg, p. 4, figs. 1-15 (these authors neglected to include the oil globule in their illustrations); larva, p. 6, fig. 19.

Haigh, 1972a: larva, p. 50, figs. 1-2.

O'Toole, 1978: egg, p. 21.

Egg:

Table 3. The oil globules of the ovarian eggs described by Gilchrist (1916) measured 0,25 mm, only marginally less than the 0,26-0,28 mm of the eggs seen by the present author.

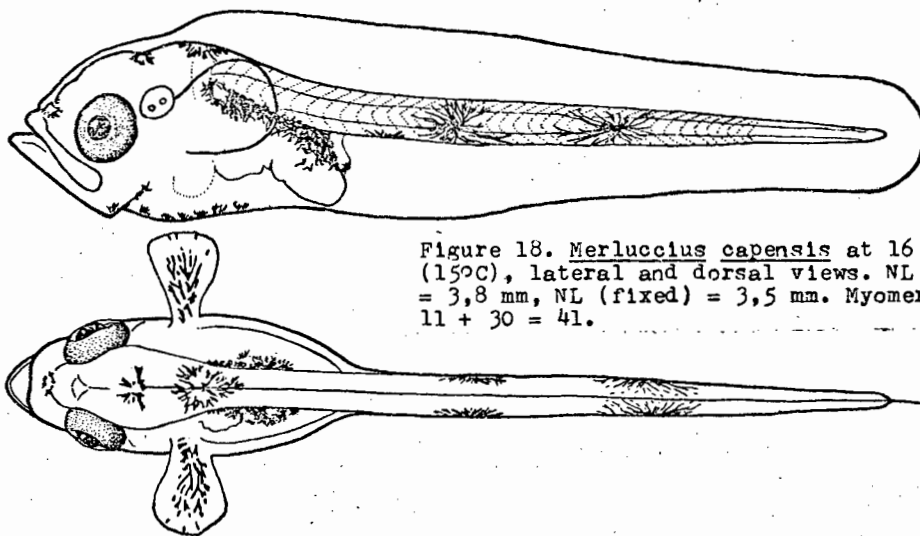


Figure 18. *Merluccius capensis* at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,8 mm, NL (fixed) = 3,5 mm. Myomeres: 11 + 30 = 41.

Figure 19. Species 1 (Carapidae) egg. Major axis 1,14 mm, minor axis 0,99 mm, oil globule 0,06 mm.

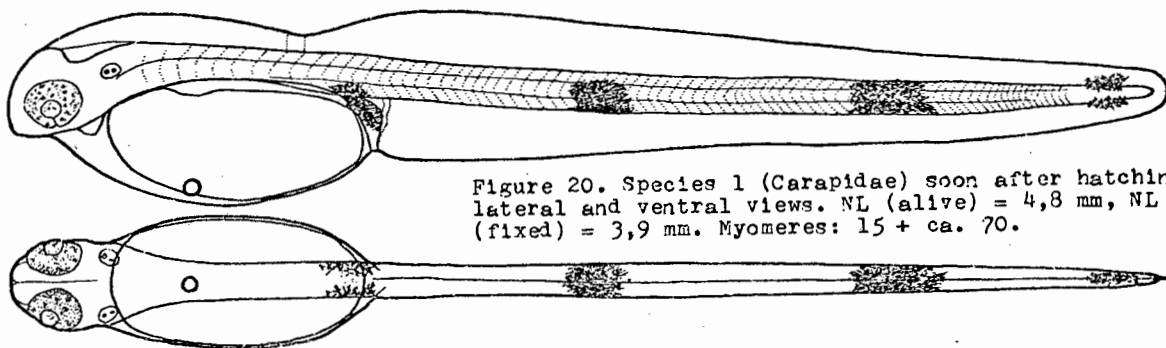
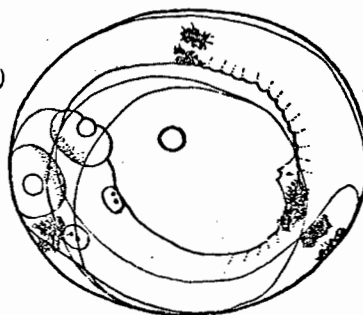


Figure 20. Species 1 (Carapidae) soon after hatching, lateral and ventral views. NL (alive) = 4,8 mm, NL (fixed) = 3,9 mm. Myomeres: 15 + ca. 70.

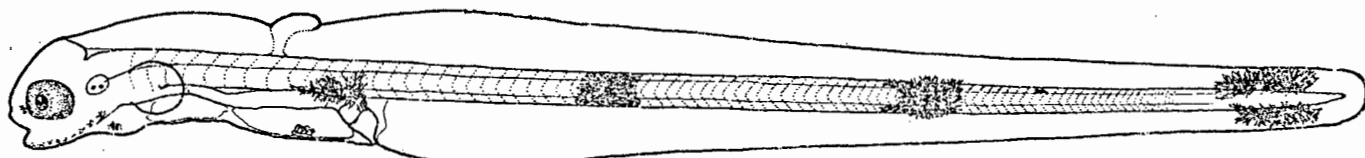


Figure 21. Species 1 (Carapidae) at 4 days (15°C). NL (alive) = 6,2 mm, NL (fixed) = 5,5 mm. Myomeres: 14 + ca. 70.

Matthews and De Jager (1951) reported an oil globule diameter of only 0,16 mm in the eggs that they artificially fertilized. O'Toole (1978) measured oil globules of 0,15-0,26 mm in eggs he collected from the plankton off Namibia. This much intraspecific variation in oil globule diameter is highly unusual, and suggests that more than one species is involved. There is general agreement concerning the diameter of the chorion: ca. 0,95-1,05 mm (although O'Toole (1978) identified eggs as small as 0,85 mm as M. capensis). If M. capensis eggs are, indeed, so variable, there is a wide overlap of dimensions with a host of other species, including the gadid, Physiculus and many perciforms.

Larva.

Figs. 16-18, table. Of the three gadiforms whose eggs were encountered here, only M. capensis bears yellow pigment in the late embryo and early larval stages. Very little individual variation was detected in the distribution of either yellow or black pigment, and the specimens illustrated serve as typical examples.

Meristics.

M. capensis: D1 11 (10-11), D2 37-40, A 37-40, Vertebrae: 51 (48-52). (Franca, 1954). The same author reported a vertebral count of 56 (55-57) for M. paradoxus. Modal vertebral counts of 49 and 54, respectively, were reported by Botha, 1970.

Geographic and seasonal distribution.

Both Merluccius species range into Angolan waters (Franca, 1954). Hakes range eastward as far as Port St. Johns (Day et al., 1970). Although M. capensis is rated "common" in False Bay (Day et al., 1970), spawning apparently occurs elsewhere: no hake eggs were collected there at any time during the year. Small numbers of eggs appeared in tows made off Three Anchor Bay in the months of April, September, and October (table 1). O'Toole (1978), in reviewing

other literature, reported year-round spawning in both Merluccius species, with a maximum from September to December.

Bearing notes.

Insufficient data are available to permit an estimate of the incubation period. The eggs that required the longest incubation hatched 60-72 h after collection (fig. 185.5). First-feeding was successful on Brachionus but none of the larvae survived beyond three weeks of age.

4.7 CARAPIDAE

No carapids have yet been recorded from the Cape Province. Three species are known from Natal: Jordanicus gracilis (Bleeker), Carapus margaretiferae (Bendahl), and C. reedi Smith (Smith, 1955). In addition, a carapid species has been taken in the SE Atlantic off Lobito, Angola (Poll, 1959: identified as Carapus imberbis (= C. acus)). At present, it cannot be determined to which, if any, of these species the material described below might be referable. It is clear that the eggs and early larvae described here are different from those referred to Carapus acus by Padoa (1956). The latter have a considerably larger oil globule and a different pattern of pigmentation. There is a much greater similarity to the egg and larva thought by Sparta (1926) to be Echiodon dentatus (reviewed by Padoa, 1956, figs. 665-666).

4.7.1 Species 1 (Carapidae) Figs. 19-22.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Fig. 19, table 3. The only egg of the Cape Peninsula inshore plankton with which this egg might conceivably be confused is that of the kingklip, Xiphiurus capensis. The carapid egg, however, is oval, rather than spherical, smaller, and very characteristically pigmented. The eggs were collected singly, not associated with any mucilaginous

matrix as has been described for some other carapid species (see Robertson, 1975a).

Larva.

Figs. 20-22, table 3. In the larval stages figured, there is a fine tuberculated texture to the entire integument. In the 4 and 8-day stages, the tubercles along the margin of the anal fin-fold and post-anal portion of the dorsal fin-fold take the form of minute denticles (not shown in the figures here). These larvae are unusual in bearing white pigment (above and below the posterior end of the notochord in all stages figured, and at the extreme tip of the vexillum in the 8-day stage).

Geographic and seasonal distribution.

A single egg was taken in Hout Bay in September; additional eggs were collected in Fish Hoek Bay in November and December (table 1).

Bearing notes.

Incubation time (15°C) is estimated to be 80 ± 10 h (fig. 185.5). In experiments to establish the age at first-feeding, 18 larvae of known ages (all between 111 ± 6 and 153 ± 6 h post-hatch, 15°C) were offered Proales. Feeding was successful in all 18 (8 larvae had full guts after the 4-h exposure to food, 10 larvae had half-full guts). Unfortunately, there were no survivors two weeks later.

4.8 OPHIDIIDAE

Only three shelf-dwelling ophidiids are known from the Cape of Good Hope, namely Dermatopsoides talboti, Bidenichthys capensis, and Xiphiurus capensis. There is good evidence for viviparity in the first two species. Smith (1943) and Cohen (1966) described horny male copulatory claspers in Dermatopsoides. Barnard (1934) reported a lack of such claspers in B. capensis, but the well-developed genital

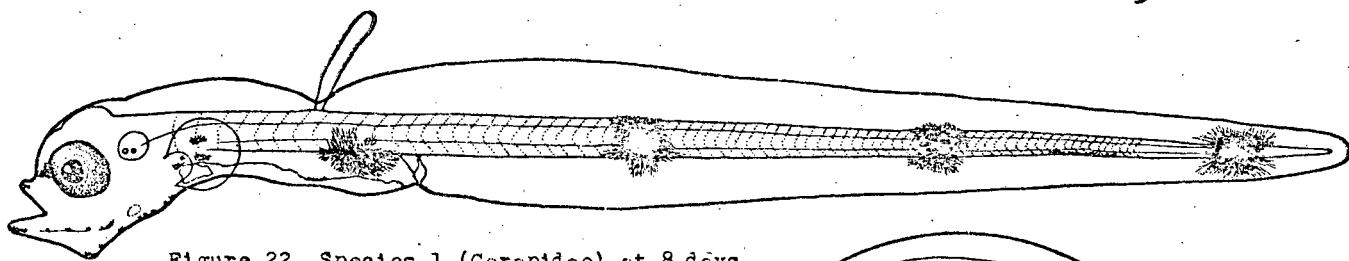


Figure 22. Species 1 (Carapidae) at 8 days (15°C). NL (alive) = 5,8 mm, NL (fixed) = 5,3 mm. Myomeres: 13 + ca. 70.

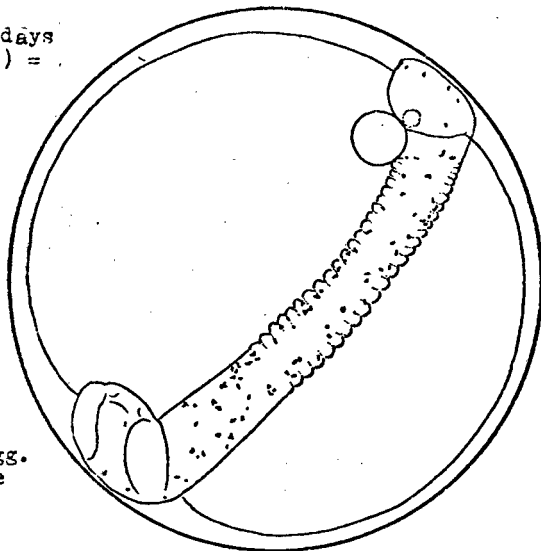


Figure 23. *Xiphiurus capensis* egg. 1,20 mm in diameter, oil globule 0,13 mm.

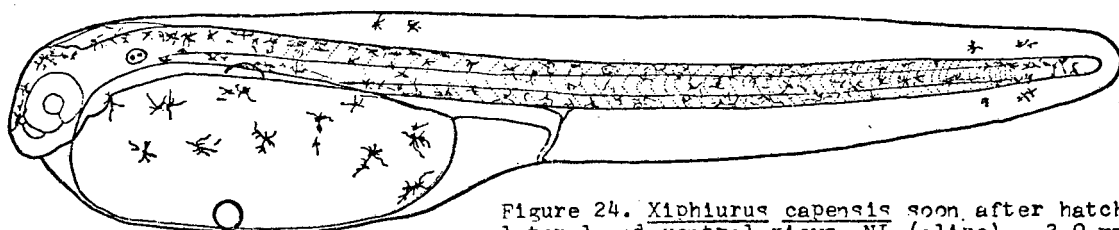


Figure 24. *Xiphiurus capensis* soon after hatching, lateral and ventral views. NL (alive) = 3,9 mm, NL (fixed) = 3,6 mm. Myomeres: 20 + ca. 45.

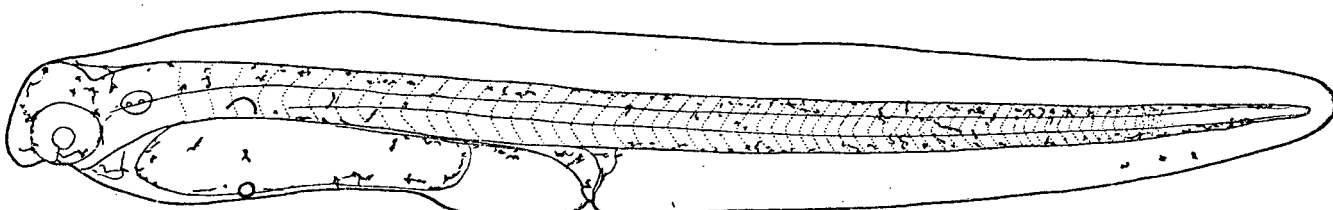
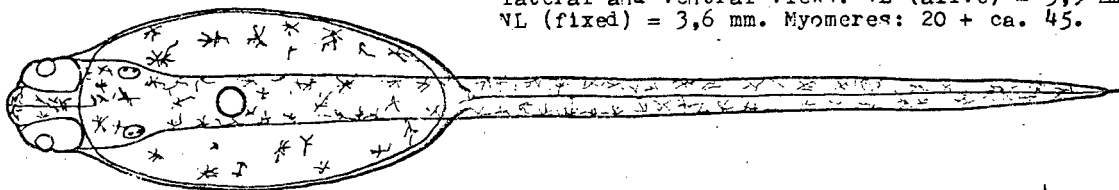


Figure 25. *Xiphiurus capensis* at 2 days (15°C). NL (alive) = 4,7 mm, NL (fixed) = 4,3 mm. Myomeres: 19 + ca. 40.

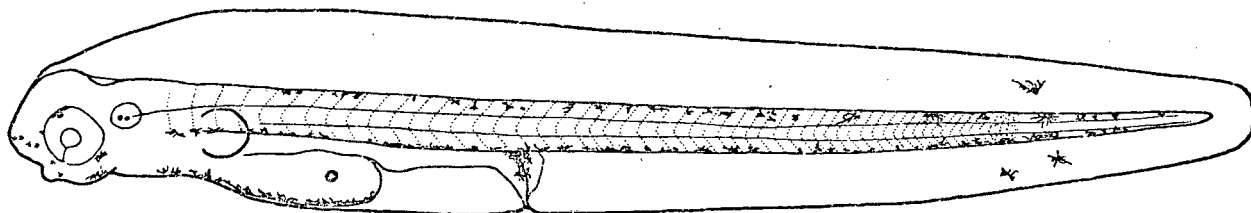


Figure 26. *Xiphiurus capensis* at 4 days (15°C). NL (alive) = 5,1 mm, NL (fixed) = 4,4 mm. Myomeres: 18 + ca. 40.

papilla in the male of this species argues for viviparity. The pelagic ophidiid eggs described below must be referred to the kingklip, X. capensis.

4.8.1 Xiphiurus capensis (kingklip) Figs. 23-28.

Previous descriptions of eggs and/or larvae.

Gilchrist & Hunter, 1919 (as Species XXVI): egg, p. 12, figs. 31-32; larva, p. 12, figs. 33-34.

Egg.

Fig. 23, table 3. The combination of single, small oil globule and moderately large, spherical egg is diagnostic.

Larva.

Figs. 24-28, table 3. Larvae are characterized by the elongated body, high myomere count, and weak development of pigment.

Meristics.

Vertebrae: 65-73, with a mode of 68 in the Walvis stock and 70 in the Cape and Southeast stocks (Payne, 1977). P 21-23, V 2 (Poll, 1959).

Geographic and seasonal distribution.

X. capensis is endemic to southern Africa, with a distribution from about 20°S in the Atlantic off Namibia (Poll, 1959) to Algoa Bay (Smith, 1965). Three stocks, more or less geographically distinct, exist over this range (Payne, 1977). The eggs were taken on both sides of the Cape Peninsula, but more regularly and in greater numbers from the Atlantic. Based on these collections (table 1), the spawning season in the area studied appears to extend from March to November, inclusive, with a possible maximum in May-June. The eggs described by Gilchrist & Hunter (1919) from Table Bay were collected in July and August. Payne (1977) observed ripe-running females only in August, September, and October.

Bearing notes.

Incubation time (15°C): 106 ± 10 h (fig. 185.7). First-feeding was very successful on Brachionus but no larvae survived more than three weeks post-hatch.

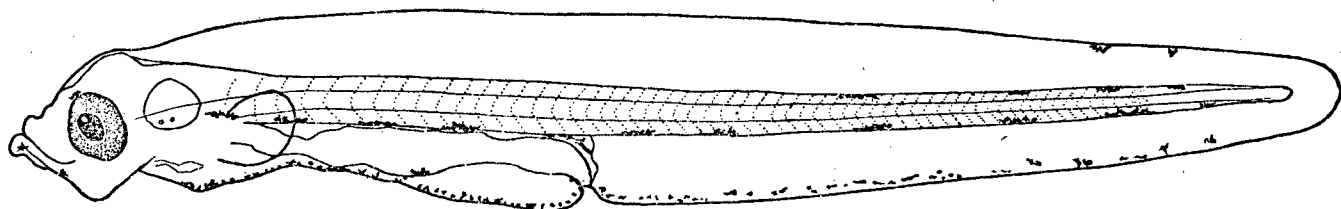


Figure 27. *Xiphiurus capensis* at 8 days (15°C). NL (alive) = 5,1 mm. NL (fixed) = 4,9 mm. Myomeres: 18 + ca. 40.

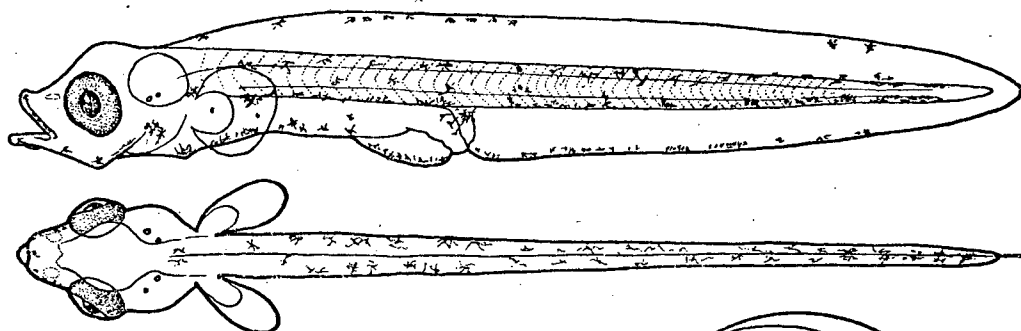


Figure 28. *Xiphiurus capensis* at 16 days (15°C), lateral and dorsal views. NL (alive) = 6,1 mm, NL (fixed) = 5,5 mm. Myomeres: 18 + ca. 40.

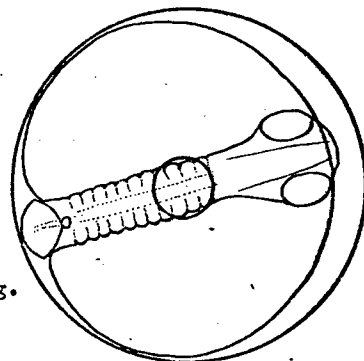


Figure 29. *Arnoglossus capensis* egg. 0,72 mm in diameter, oil globule 0,12 mm.

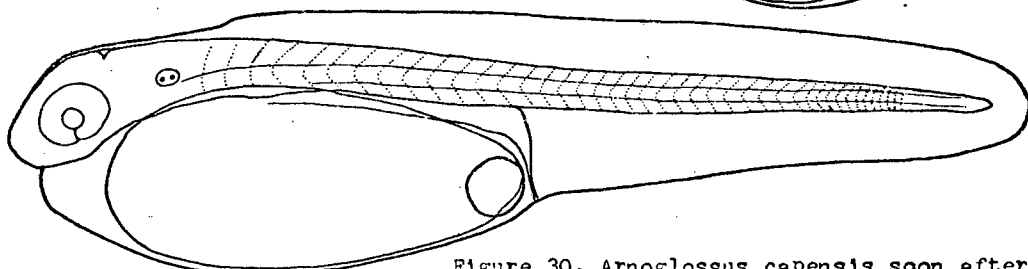


Figure 30. *Arnoglossus capensis* soon after hatching, lateral and ventral views. NL (alive) = 2,4 mm, NL (fixed) = 2,2 mm. Myomeres: 15 + ca. 25.

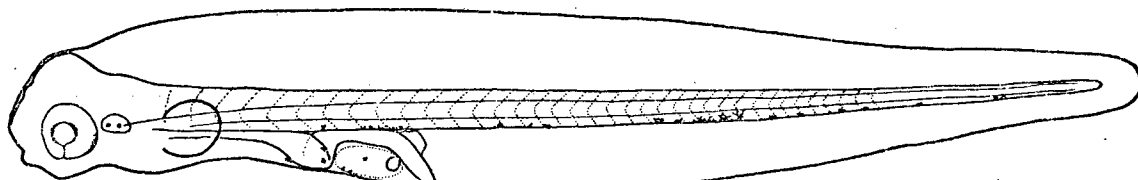


Figure 31. *Arnoglossus capensis* at 4 days (15°C). NL (alive) = 3,4 mm, NL (fixed) = 3,2 mm. Myomeres: 11 + 27 = 38.

4.9 BOTHIDAE

Only two of the 16 bothids known from southern Africa occur in Cape of Good Hope waters: Arnoglossus capensis and Mancopsetta milfordi. The latter is a bathyl species (Penrith, 1965), probably rare.

4.9.1 Arnoglossus capensis (Cape flounder) Figs. 29-32.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904: egg, p. 133; larva, p. 133, fig. 36.

Gilchrist, 1916: egg, p. 16; larva, p. 16, fig. 12.

Gilchrist & Hunter, 1919: egg, p. 8; larva, p. 8.

Egg.

Fig. 29, table 3. The egg can be distinguished from all known Cape Peninsula eggs on the basis of chorion and oil globule dimensions.

Larva.

Figs. 30-32, table 3. The newly-hatched larva bears spots of salmon-coloured pigment but lacks melanophores. The latter only appear after about 3 days (15°C), as do patches of yellow pigment, usually in association with the salmon spots. Not shown in the drawings are the minute (up to 50 µm long) denticles that occur on the margins of the dorsal and anal fin-folds. These were developed by the 4-day stage and persisted at least through the 8th day.

Meristics.

D 85-100, A 70-80 (Smith, 1965).

Geographical and seasonal distribution.

Poll (1959) indicated that A. capensis ranges northward into the E. Atlantic as far as Gambia. Day et al. (1970) placed the eastern limit of its distribution in Natal. There appears to be year-round spawning in False Bay. Practically all the eggs taken on the Atlantic side of the Cape Peninsula were netted from March to June (table 1). Gilchrist (1904) took an egg in False Bay in November;

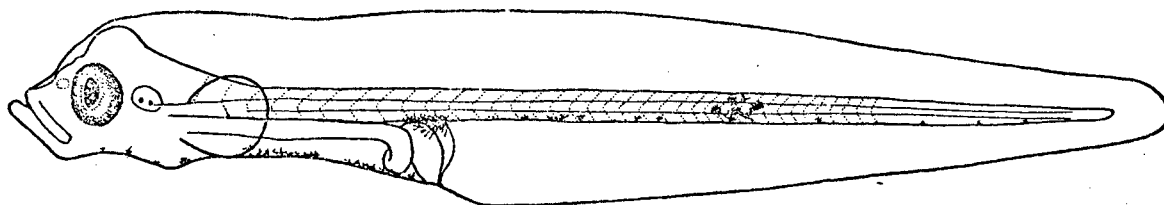


Figure 32. Arnoglossus capensis at 8 days (15°C). NL (alive) = 3,6 mm, NL (fixed) = 3,3 mm. Myomeres: 11 + 27 = 38.

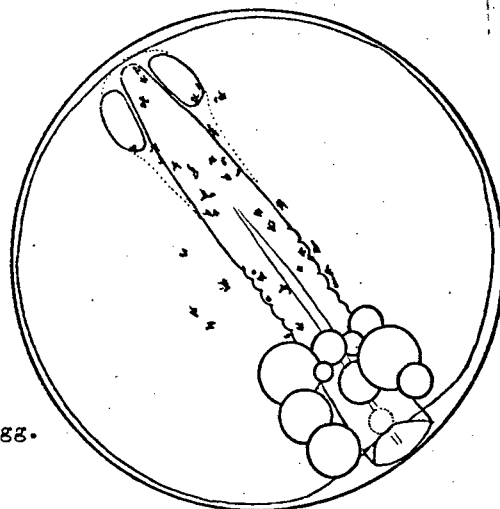


Figure 33. Austroglossus microlepis egg. 0,88 mm diameter.

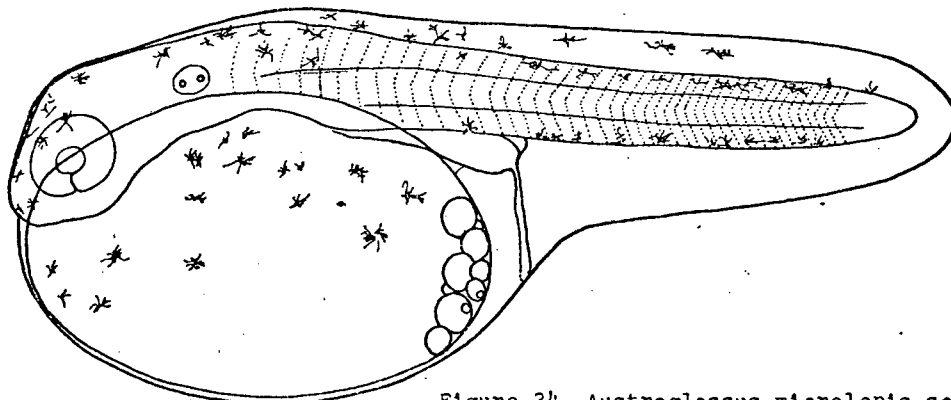


Figure 34. Austroglossus microlepis soon after hatching, lateral and ventral views. NL (alive) = 1,8 mm, NL (fixed) = 1,7 mm. Myomeres: 15 + ca. 30.

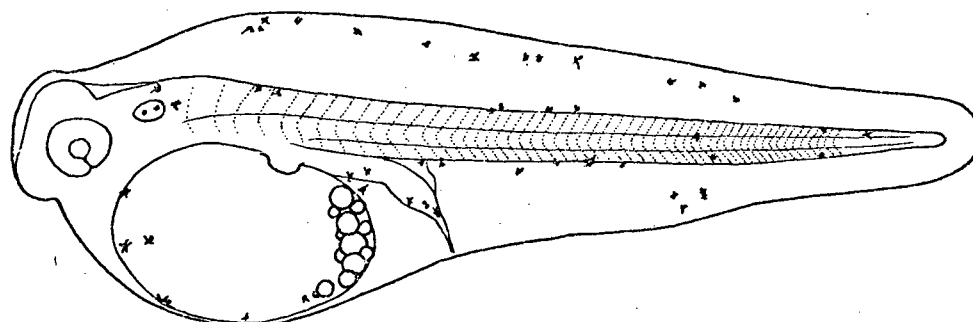
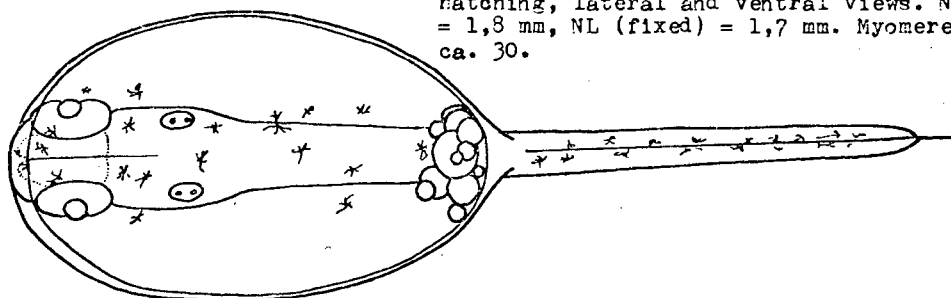


Figure 35. Austroglossus microlepis at 2 days (15°C). NL (alive) = 2,8 mm, NL (fixed) = 2,6 mm. Myomeres: 15 + ca. 40.

Gilchrist & Hunter (1919) took eggs in Table Bay in October and March.

Bearing notes.

The species has a relatively short incubation time: 45 ± 10 h at 15°C (fig. 185.8). Brachionus appears to be too large a first food for A. capensis. Feeding on Proales was sporadic, however, and survival beyond an age of two weeks was not achieved.

4.10 SOLEIDAE

Day et al. (1970) listed five sole species from False Bay: Heteromycteris capensis, Austroglossus microlepis¹, Synaptura kleini, Solea bleekeri, and Solea fulvomarginata. The first three species mentioned extend into the Atlantic as far north as Walvis Bay; the latter two are restricted to the Indian Ocean.

Gilchrist (1903, 1904, 1916) and Gilchrist & Hunter (1919) described five kinds of sole eggs from the western Cape Province. They were able to identify three of them (H. capensis, A. microlepis, and Synaptura kleini) and designated the remaining two as Species X (Gilchrist, 1903; 1916) and Species XVII (Gilchrist, 1904; 1916). It is suggested here that Gilchrist's Species X may be referred to Solea bleekeri and his Species XVII (Species 2 of the present author) may be referred to Solea fulvomarginata.

4.10.1 Austroglossus microlepis (west coast sole) Figs. 33-38.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1916 (as Synaptura microlepis): egg, p. 16.

footnote: 1. Barnard (1925-1927) placed A. pectoralis in False Bay and not A. microlepis. Peter Zoutendyk (CSIR, Univ. of Cape Town, pers. comm., 1977) seriously doubted that A. pectoralis ranges as far west as False Bay.

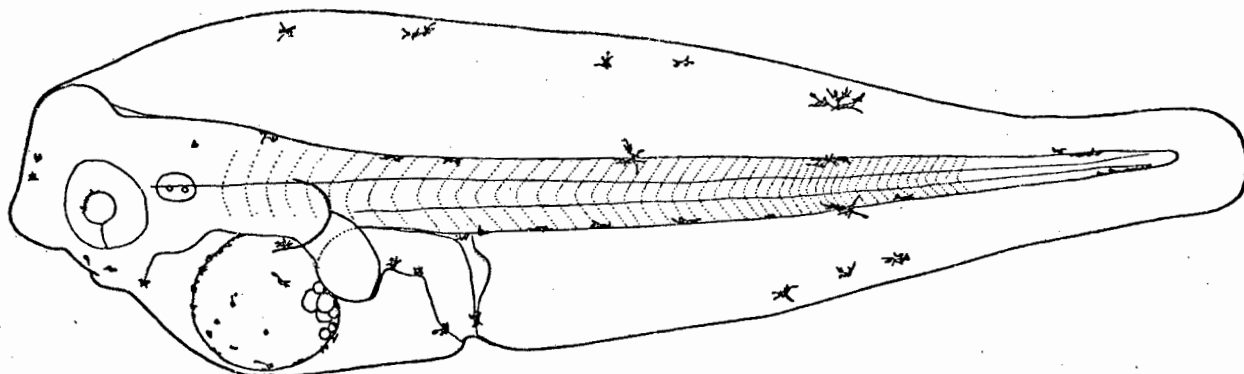


Figure 36. Austroglossus microlepis at 4 days (15°C). NL (alive) = 2,7 mm, NL (fixed) = 2,5 mm. Myomeres: 12 + 40 = 52.

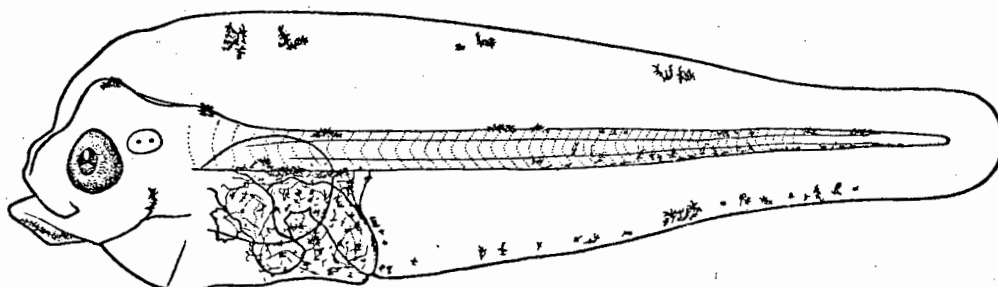


Figure 37. Austroglossus microlepis at 8 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,7 mm. Myomeres: 11 + 40 = 51.

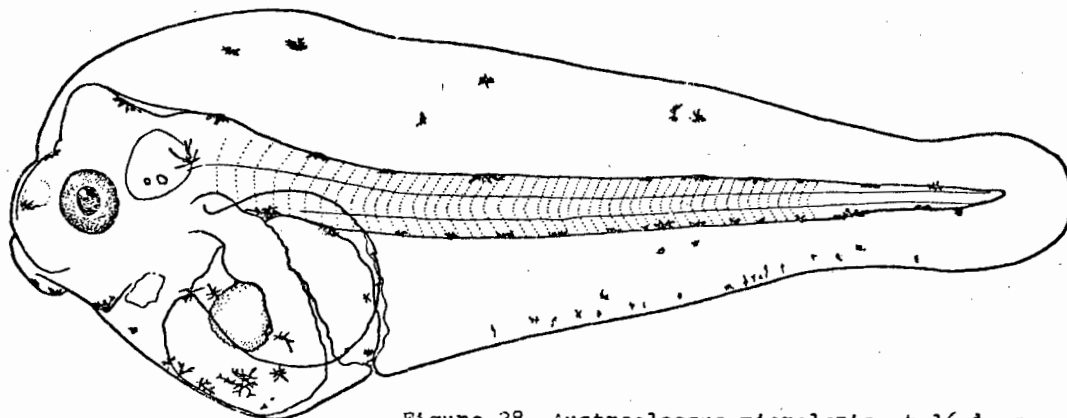


Figure 38. Austroglossus microlepis at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,3 mm, NL (fixed) = 3,5 mm. Myomeres: 10 + 40 = 50.

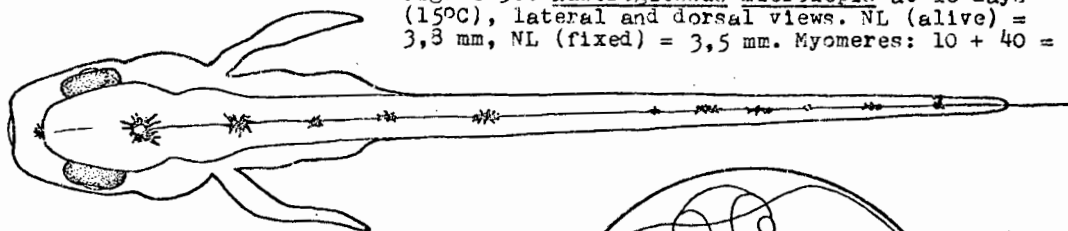
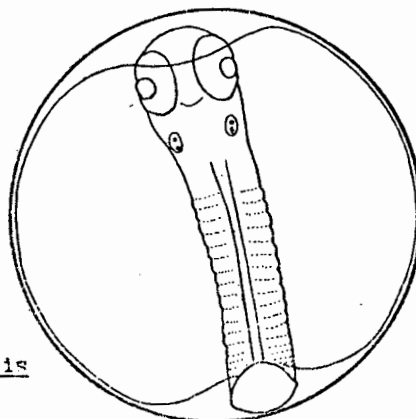


Figure 39. Heteromysteris capensis egg. 1,01 mm in diameter.



Gilchrist & Hunter, 1919 (as Synaptura microlepis): egg, p. 7, fig. 18; larva, p. 7, fig. 19.

O'Toole, 1977: larva, figs. 2-3.

Egg.

Fig. 33, table 3. The 12-20 oil globules are arranged in a single cluster, which becomes positioned in the posterior end of the yolk sac as hatching nears. Some combining of globules was seen to take place, but even some 4-day-old (15°C) larvae were multiglobulate.

Larva.

Figs. 34-38, table 3. Once the oil globules have been absorbed the larva is very similar in appearance to Heteromycteris capensis larvae of the same age. In living A. microlepis larvae near the first-feeding stage, the fin-fold xanthophores have a slightly orange hue; in H. capensis, these xanthophores are straw-yellow. There is considerable variation in xanthophore distribution in both species. The difference in post-anal myomere count (ca. 40 in A. microlepis, ca. 30 in H. capensis) will help to distinguish preserved specimens of the two species. For descriptions of older larvae, the reader should refer to O'Toole (1977).

Meristics.

D ca. 95, A ca. 75. (Smith, 1965).

Geographic and seasonal distribution.

O'Toole (1977) stated that this sole is fished commercially as far north as 19°S (Rocky Point, Namibia). False Bay is the eastern limit of its range (Day et al., 1970). From collection records presented here (table 1), it is difficult to delineate the spawning season: eggs were taken in the Atlantic in the months of March, June, September, October, and November. A single egg was taken in False Bay in November. It is proposed that the species spawns in the Cape Peninsula area from March to November, with a maximum in September-October. Gilchrist & Hunter (1919)

netted eggs in Table Bay in August and September. Of Namibia, O'Toole (1977) took A. microlepis larvae from September to January, inclusive, but none in February and March (no collecting was conducted between 5 April and 13 August).

Bearing notes.

Incubation time (15°C): 80 ± 10 h (fig. 185.9). First-feeding was successful on Brachionus, but none of the larvae placed in rearing tanks survived more than about three weeks.

4.10.2 Heteromycteris capensis (Cape sole) Figs. 39-45.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Achirus capensis): egg, p. 191, fig. 16.

Gilchrist, 1903 (as Species V): egg, p. 197; larva, p. 197, fig. 27.

Gilchrist, 1916 (as Achirus capensis): egg, p. 17, fig. 13; larva, p. 17, fig. 13.

Egg.

Fig. 39, table 3. The only egg encountered during this study that is likely to be confused with the egg of H. capensis is that of the scorpaenid, Coccotropsis gymnotoderma, which is similarly pigmented and also lacks an oil globule. The two eggs appear to be distinguishable on the basis of size.

Larva.

Fig. 40-45, table 3. Early larvae of H. capensis might be confused with those of Austroglossus microlepis (and probably, A. pectoralis) once the yolk sac is absorbed. Both H. capensis and A. pectoralis (Gilchrist & Hunter, 1919: 8) lack the orange pigment that develops on A. microlepis during the yolk-sac stage. The lower myomere count of H. capensis should separate it from both Austroglossus species.

Completion of metamorphosis (definitive fin-ray counts, end of eye migration, benthic habits) occurred in some reared specimens at standard lengths as small as 7.0 mm. (alive). 10 mm might be taken as a more typical size at completion of metamorphosis, but it is difficult to say to what extent rearing conditions determine this feature. Perhaps as many as 5% of the reared H. capensis failed to

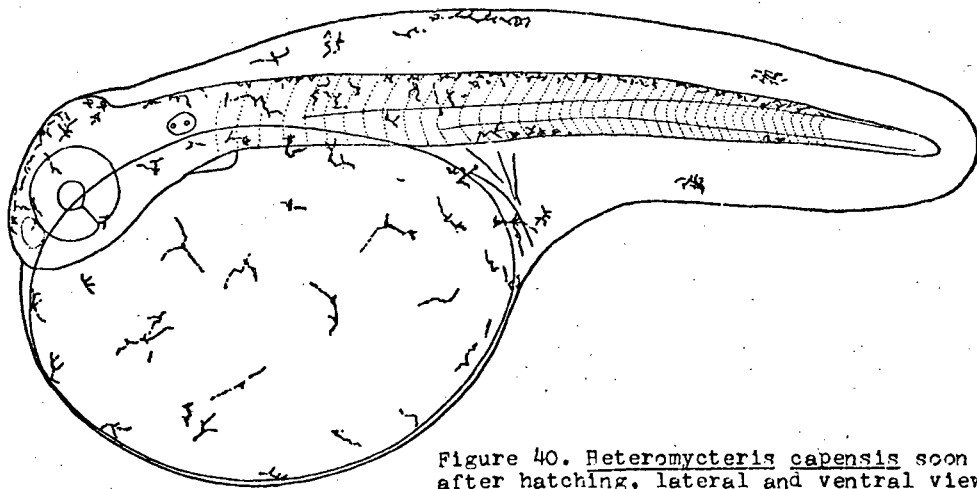


Figure 40. *Heteromycteris capensis* soon after hatching, lateral and ventral views. NL (alive) = 2,1 mm, NL (fixed) = 1,7 mm. Myomeres: 15 + ca. 30.

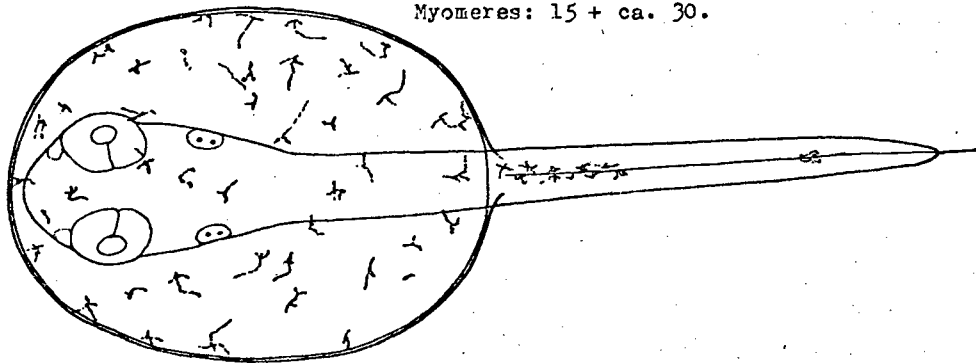


Figure 41. *Heteromycteris capensis* at 2 days (15°C). NL (alive) = 2,5 mm, NL (fixed) = 2,5 mm. Myomeres: 14 + ca. 30.

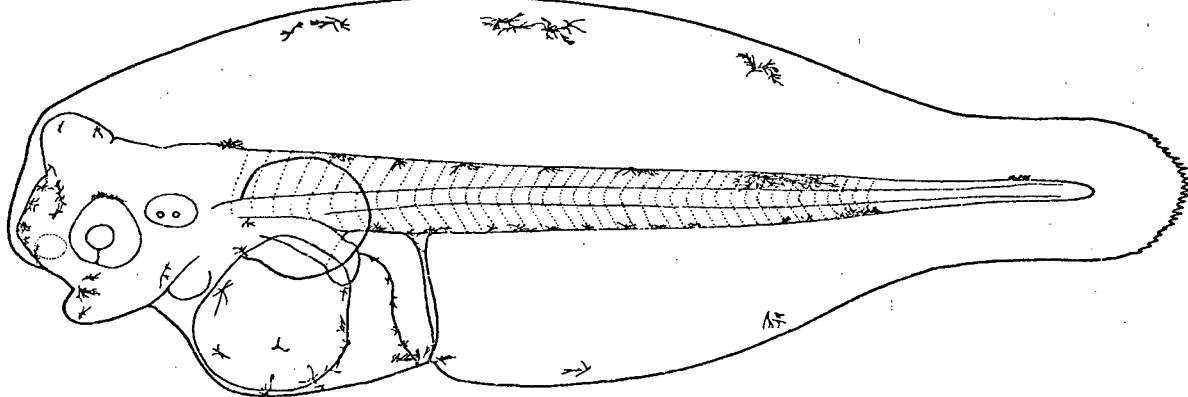


Figure 42. *Heteromycteris capensis* at 4 days (15°C). NL (alive) = 2,6 mm, NL (fixed) = 2,3 mm. Myomeres: 10 + 30 = 40.

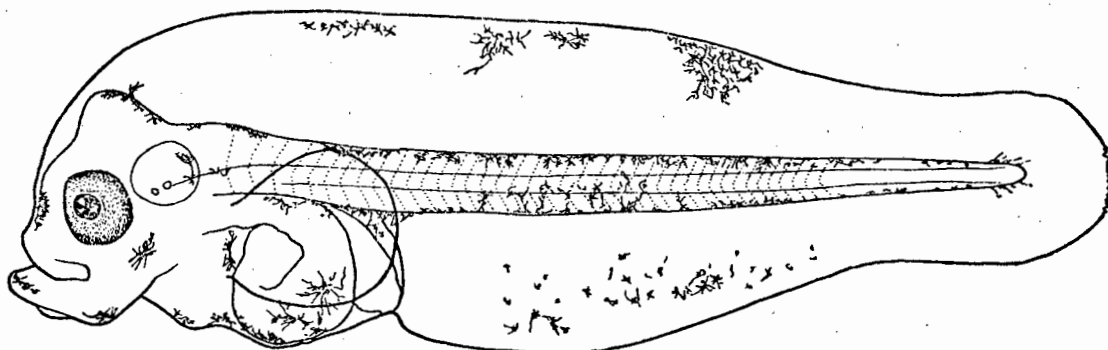


Figure 43. *Heteromyceteris capensis* at 8 days (15°C). NL (alive) = 3,0 mm, NL (fixed) = 2,7 mm. Myomeres: 10 + 31 = 41.

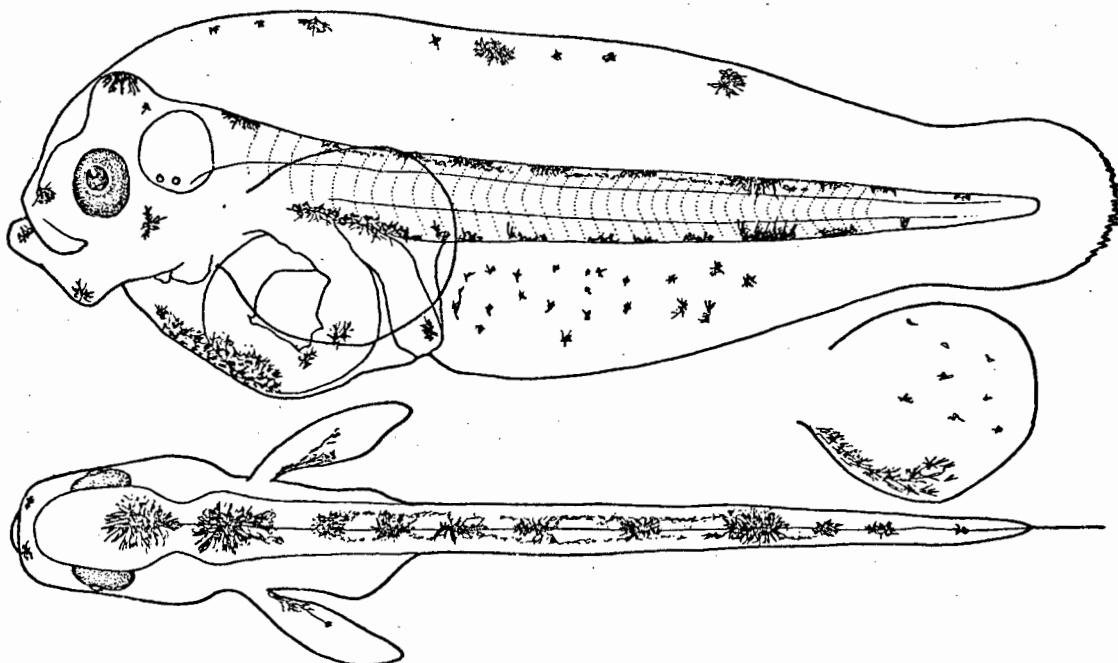


Figure 44. *Heteromyceteris capensis* at 16 days (15°C), lateral view, dorsal view, and fin detail. NL (alive) = 4,0 mm, NL (fixed) = 3,6 mm. Myomeres: 10 + 29 = 39.

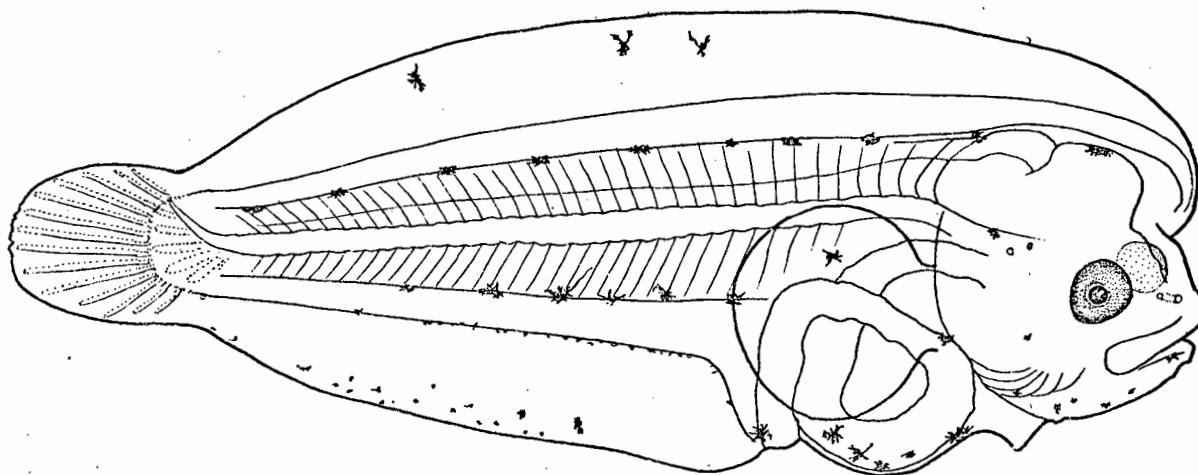


Figure 45. *Heteromyceteris capensis* at 32 days (15°C). Onset of eye migration. SL (alive) = 6,6 mm, SL (fixed) = 6,2 mm.

undergo eye migration, and remained ambi-ocular as long as they were kept (up to 18 months).

Meristics.

D 92-101, A 64-70, Vertebrae: 7-8 + 32-33 = 39-41 (this study).

Geographic and seasonal distribution.

H. capensis occurs in shallow water, often in estuaries, from Walvis Bay to Natal (Smith, 1965). It is not included in Wallace's (1975a) checklist of Natal estuarine fishes, and is probably rare east of the Cape Province. Eggs were collected in False Bay every month except August; none were ever taken along the Atlantic side of the Cape Peninsula (although a few were present in a tow made in Saldanha Bay in August). Spawning in False Bay is heaviest in spring and summer, particularly October to February, inclusive (table 1)..

Rearing notes.

The Cape sole is among the hardiest and most easily reared marine teleost species encountered in Cape Peninsula waters. Incubation time at 15°C is estimated to be 80 ± 10 h (fig. 185.10). Both Brachionus and Proales were taken avidly at first-feeding, about 145-195 h post-hatch (Part 1 of this thesis, fig. 7). Eye migration usually begins about the third week, the larvae take up a predominantly benthic existence after a month and metamorphosis is complete 2-4 weeks later (15°C).

4.10.3 Synaptura kleini (lace sole) Figs. 46-52.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Species VII): egg, p. 198; larva, p. 198, figs. 29-31.

Gilchrist, 1916 (as Solea capensis): egg, p. 17; larva, p. 17, fig. 14.

not Thomopoulos, 1956 (as Solea kleini or S. hispidia): egg, p. 6, fig. 15; larva, p. 7, fig. 16.

?Aboussouan, 1972 (as Solea kleini): larva, p. 991, fig. 12. (The meristics of Aboussouan's larvae are those of S. kleini, but the arrangement of melanophores in two incomplete vertical bands was never seen in the many larvae reared during the present study.)

Figure 46. *Synaptura kleini* egg.
1,34 mm in diameter.

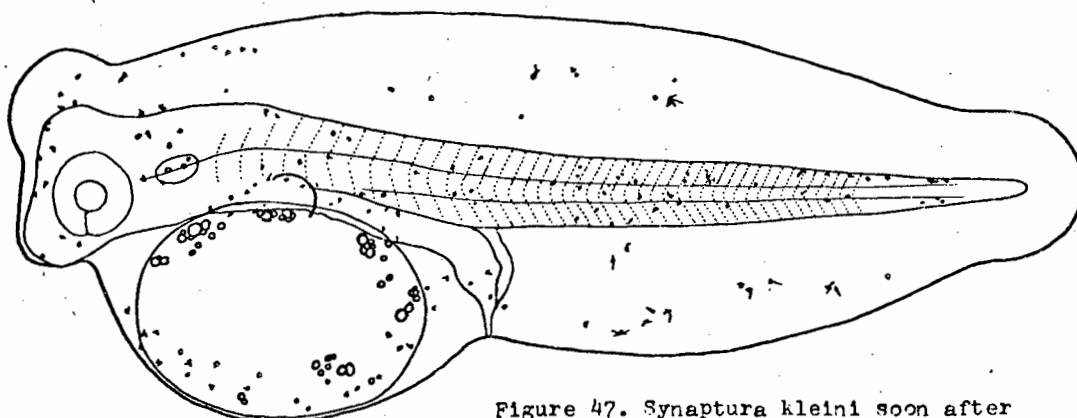
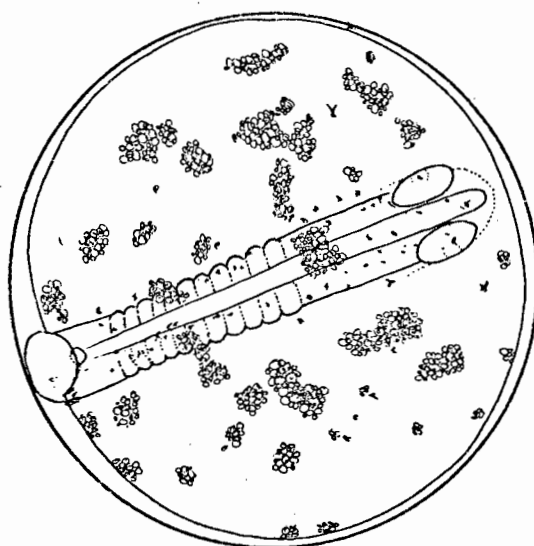


Figure 47. *Synaptura kleini* soon after hatching, lateral and ventral views.
NL (alive) = 3,4 mm, NL (fixed) = 3,0 mm. Myomeres: 14 + 31 = 45.

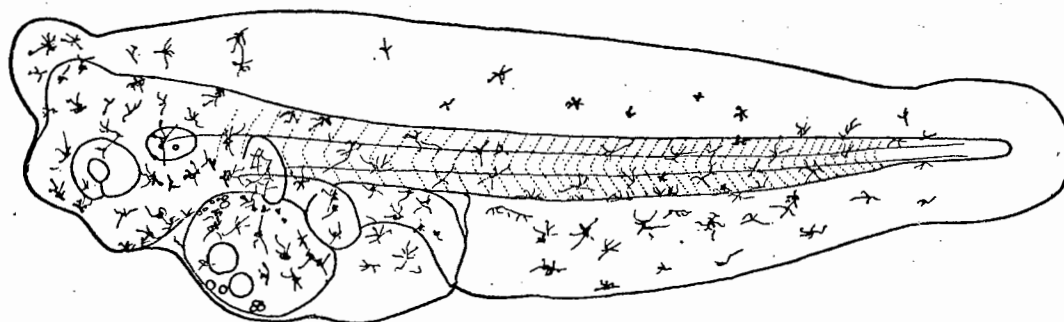
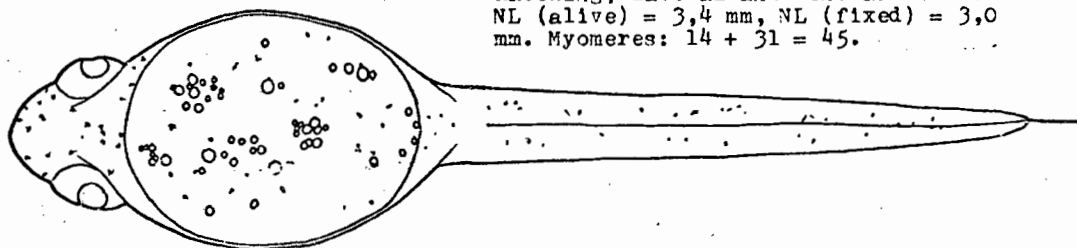


Figure 48. *Synaptura kleini* at 2 days (15°C). NL (alive) = 3,6 mm, NL (fixed) = 3,3 mm. Myomeres: 12 + 33 = 45.

Egg.

Fig. 46, table 3. The egg of S. kleini at the earliest stages of development appears to lack oil globules. The egg is, in fact, globulated, but the globules are extremely minute. They are at first evenly distributed around the yolk, giving it a fog-like quality. They gradually coalesce into irregular clumps, each consisting of hundreds of tiny globules (fig. 46). At hatching there are still some hundred globules left; these continue to coalesce as the yolk-sac is absorbed. The egg appears to be consistently smaller than that of the unidentified soleid, Species 2.

Larva.

Figs. 47-51, table 3. The living larva is unmistakable, with its heavy yellow/orange pigmentation. At metamorphosis, which occurs at about 6 weeks (15°C) at a total length (alive) of 7-9 mm, the orange pigment is replaced by white, with varying amounts of black (the latter being concentrated along the dorsal and anal fin margins). Most of the juvenile soles, including those kept in black-sand tanks, were predominantly white (with black margins, and orange papillae on the underside of the head) up to a total length of about 3 cm, when the colour changed increasingly to grey.

Meristics.

D 75-90, A 60-70 (Smith, 1965). D 81-95, A 65-74, Vertebrae: 45-49 of which 9-10 are precaudal (Chabanaud, 1929: S. African material). Specimens reared during this study yielded vertebral numbers slightly lower than this: 9-10 + 33-35 = 43-45. These values fall in the range that Chabanaud gave for Mediterranean samples.

Geographic and seasonal distribution.

S. kleini ranges from the Mediterranean to South Africa (Durban) (Chabanaud, 1929; Collignon et al., 1957: as Solea capensis; Day et al., 1970), but records from the E. Atlantic are rare. In the present study, eggs were collected from October to April, inclusive, in False Bay only (table 1).

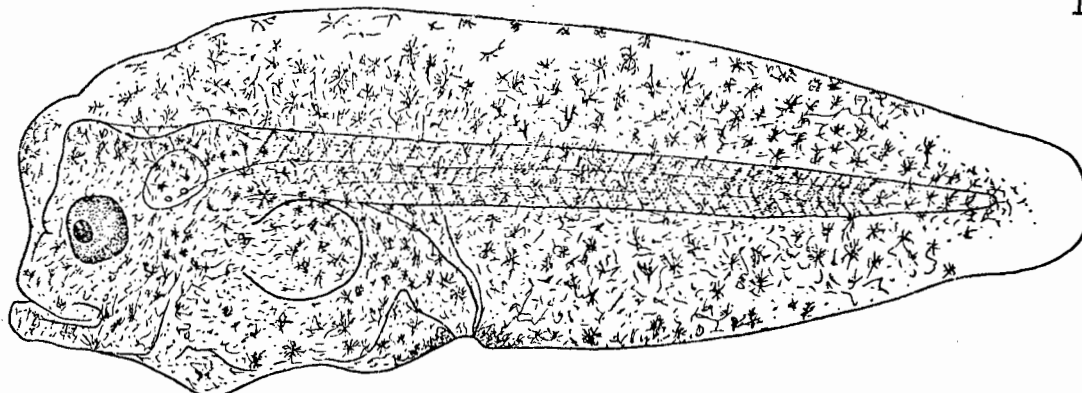


Figure 49. Synaptura kleini at 8 days (15°C). NL (alive) = 4,4 mm, NL (fixed) unavailable, specimen damaged prior to fixing. Myomeres: 11 + 32 = 43.

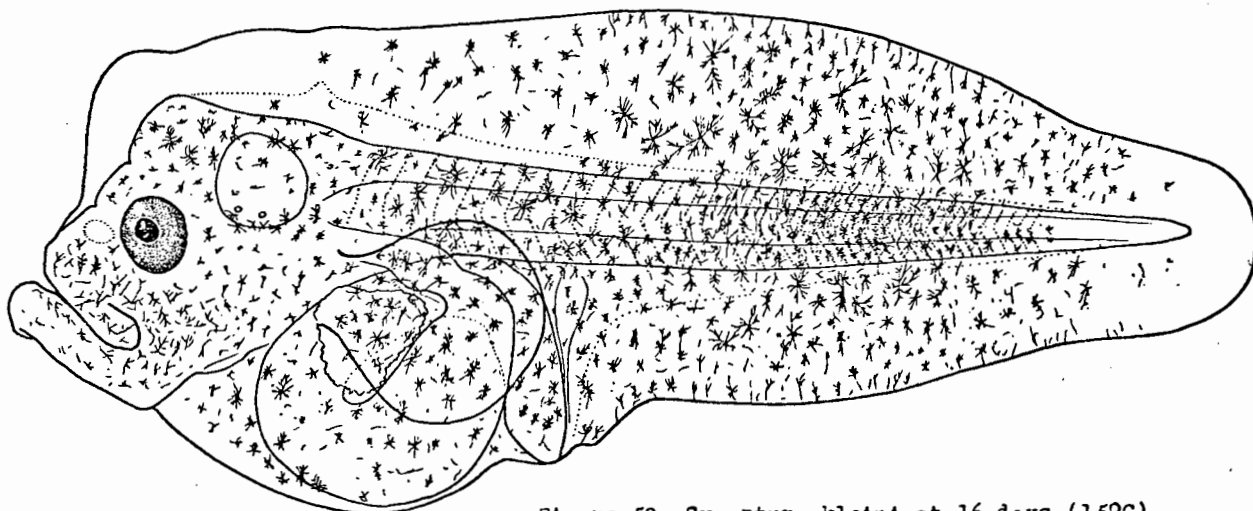


Figure 50. Synaptura kleini at 16 days (15°C), lateral and dorsal views. NL (alive) = 5,5 mm, NL (fixed) = 5,1 mm. Myomeres: 10 + 32 = 42.

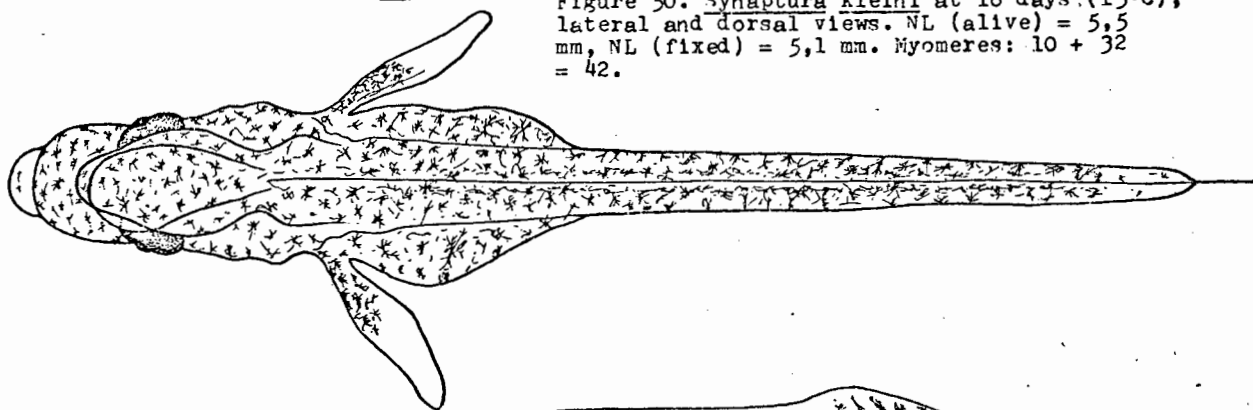
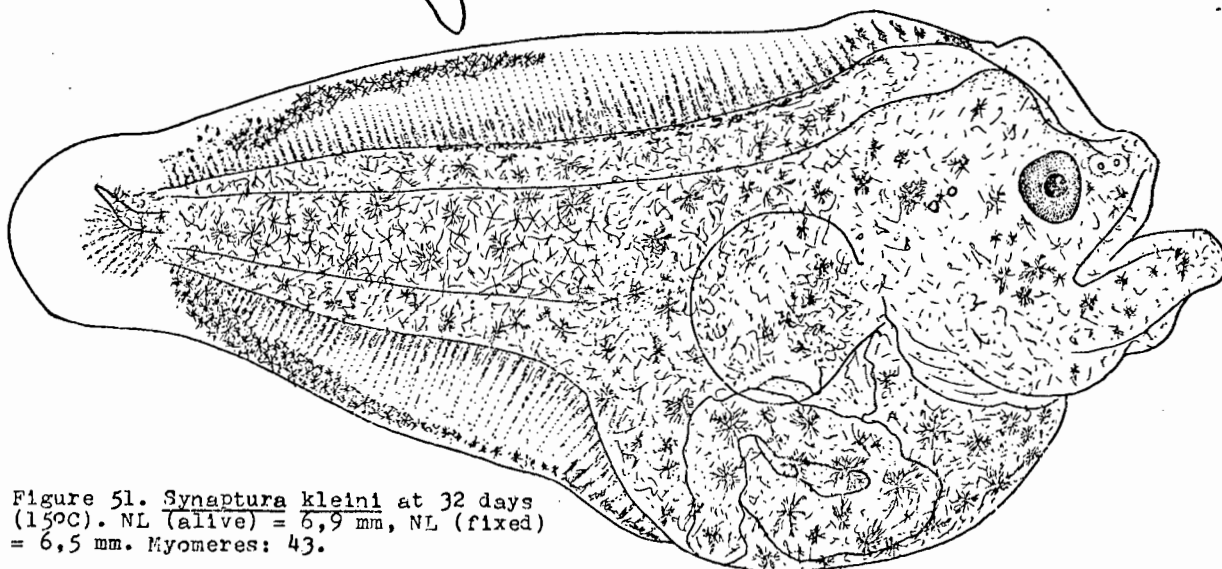


Figure 51. Synaptura kleini at 32 days (15°C). NL (alive) = 6,9 mm, NL (fixed) = 6,5 mm. Myomeres: 43.



Bearing notes.

Incubation time (15°C): 100 ± 10 h (fig. 185.11). Several batches of this sole were reared through metamorphosis using Brachionus as first food. One 8-day-old larva was seen with the tail of an 8-day-old Trulla capensis projecting from its mouth. It is probable that this species can first-feed on Artemia nauplii. Age-at-optimal-first-feeding was determined to be 154 h post-hatch (15°C) with 50% of larvae capable of first-feeding as early as 118 h and as late as 189 h (Part 1 of this thesis, fig. 7). Juveniles measured 3-4 cm SL at an age of 6 months (15°C).

4.10.4 Species 2 (Soleidae) Figs. 53-55.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904 (as Species XVII): egg, p. 140, fig. 45; larva, p. 140.

Notes on identification.

By elimination, this egg must be referred either to Solea bleekeri or S. fulvomarginata.

Egg.

Fig. 53, table 3. Prior to the point when the embryo extends 180° around the yolk, the egg of this sole has several features in common with, and could be confused with, the egg of Synaptura kleini. It appears to be consistently larger, however. Near the 180° stage, a brick-red pigment appears on the embryonic body, and by hatching, covers the entire yolk sac, as well. S. kleini is yellow at this stage.

Larva.

Figs. 54-55, table 3. The red pigment in the late embryo and early larva (at least through the 16th day, post-hatch) is the most noteworthy characteristic. The larvae still bear a pink hue after several months in formalin.

Meristics.

Solea bleekeri: D ca. 60-75, A 45-55 (Smith, 1965). Two recently metamorphosed S. bleekeri (both 4.65 mm SL) from Swartkops Estuary (sent to the author by Roy Melville-

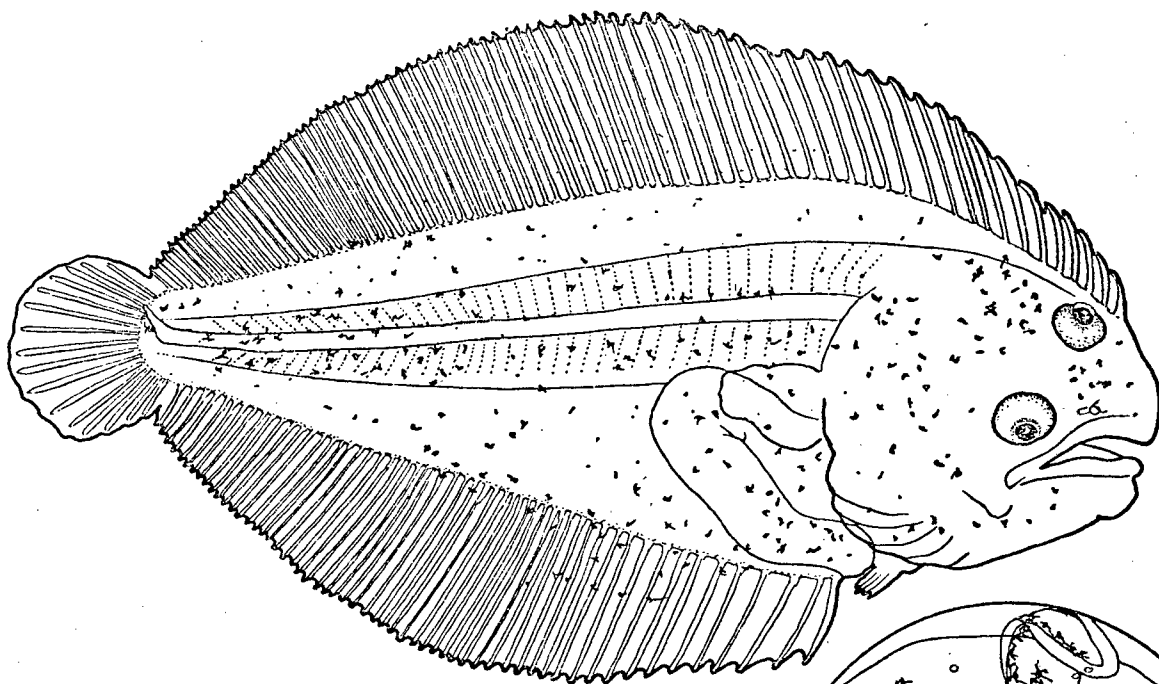


Figure 52. *Synaptura kleini* at 45 days (15°C).
SL (alive) = 8,3 mm, SL (fixed) = 7,8 mm.

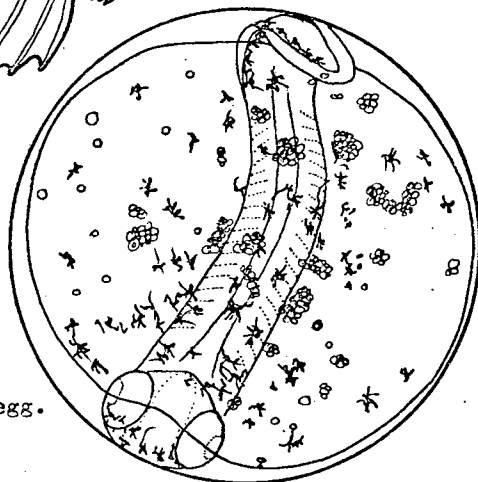


Figure 53. Species 2 (Soleidae) egg.
1,52 mm in diameter.

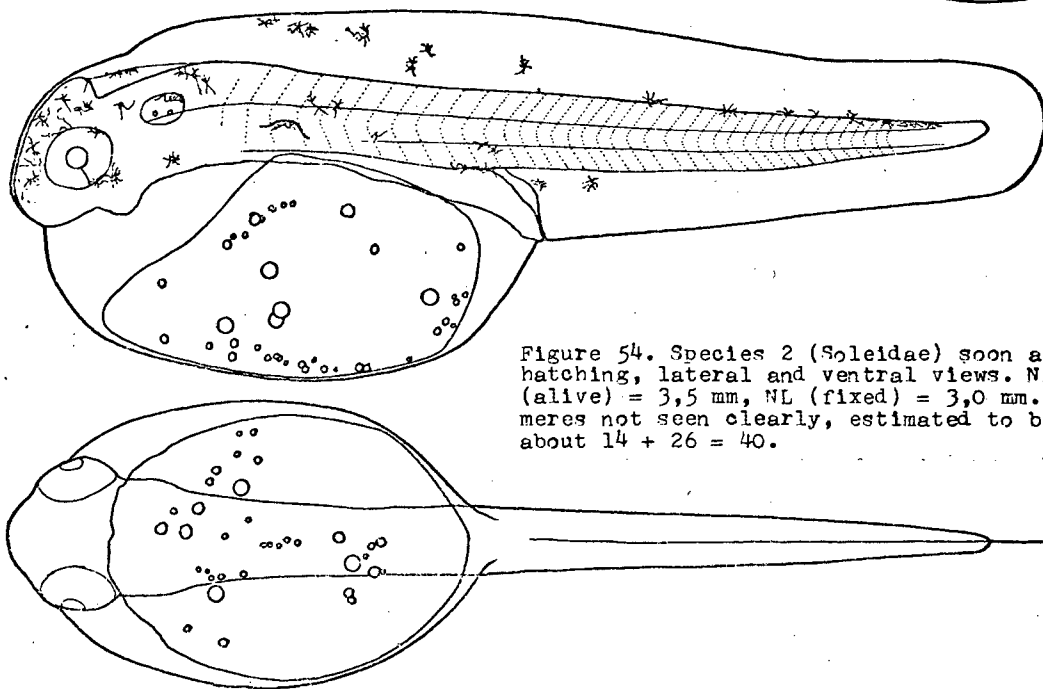


Figure 54. Species 2 (Soleidae) soon after hatching, lateral and ventral views. NL (alive) = 3,5 mm, NL (fixed) = 3,0 mm. Myomeres not seen clearly, estimated to be about $14 + 26 = 40$.

Smith, Univ. of Port Elizabeth) yielded these counts: D 65-66, A 48-50, Vertebrae: 8-9 + 23-24 = 32-33.

A juvenile sole (19.4 mm SL) collected by the author at Muizenberg (False Bay) in March and kept 3 weeks in an aquarium yielded the following counts: D 71, A 59, P_r 3, P₁ 3 (pectorals equal and short: 1.6% of SL), Lateral line (ocular side, counting from the cleithrum out onto the caudal fin) 112, Vertebrae: 8 + 35 = 43. It is presumed to be Solea fulvomarginata, although fin-ray counts fall below the range given by Smith (1965: D 73-80, A 60-65). The specimen died in the tank and was not recovered until the following day. It was by then not clear if a membrane connection had existed between the caudal fin and the dorsal and anal fins.

Due to poor fixation of the author's only specimens of Species 2, it is now impossible to determine the exact myomere count. The values given in the captions to figs. 54 and 55 were taken from the rough illustration and need to be confirmed. Based on these tentative myomere counts, Species 2 is more likely to be Solea fulvomarginata than S. bleekeri.

Geographic and seasonal distribution.

Solea bleekeri and S. fulvomarginata are both endemic to Southern Africa, ranging from False Bay to Delagoa Bay in the case of the former, and False Bay to Port St. Johns in the case of the latter (Day et al., 1970). The eggs described above were taken in very small numbers in False Bay in November and February (table 1). The egg figured by Gilchrist (1904) was also taken in False Bay in November. S. bleekeri is thought to spawn from June to August, inclusive, in the St. Lucia estuary (Wallace, 1975b); October to February, inclusive, in the Swartkops Estuary (Melville-Smith, 1978). No data are available regarding the spawning season of S. fulvomarginata.

Rearing notes.

Most of the available material was sacrificed for the illustrations. The two larvae kept beyond first-feeding (Brachionus) always remained within a few millimetres of the water surface and were very sluggish. 15°C may be near the lower thermal limit for this summer spawner.

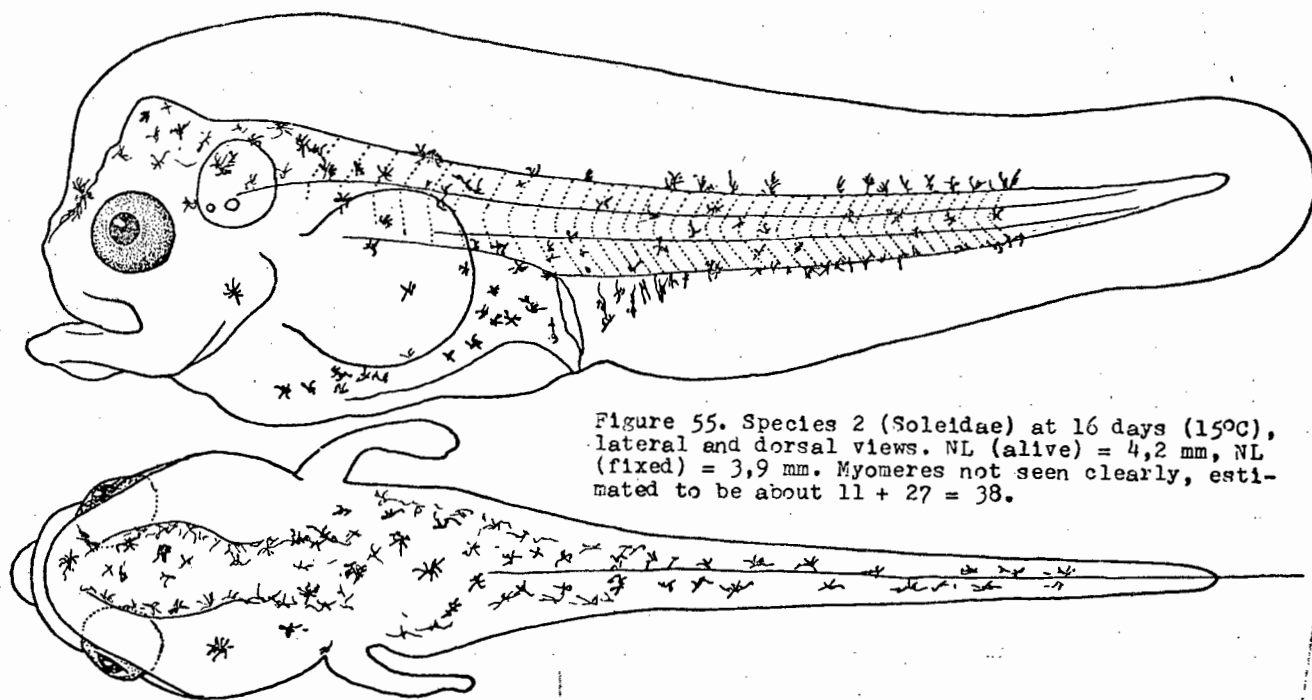


Figure 55. Species 2 (Soleidae) at 16 days (150C), lateral and dorsal views. NL (alive) = 4,2 mm, NL (fixed) = 3,9 mm. Myomeres not seen clearly, estimated to be about $11 + 27 = 38$.

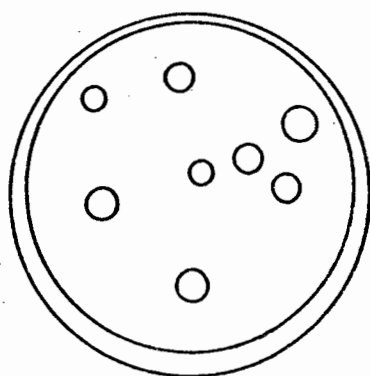


Figure 56. *Trulla capensis* egg. 0,75 mm in diameter.

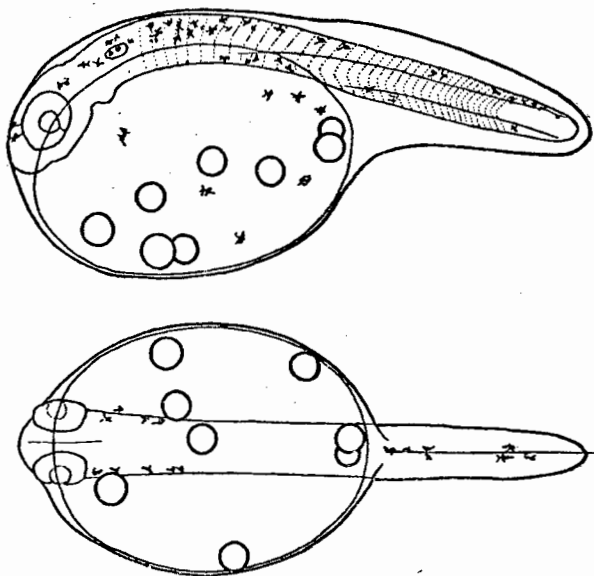


Figure 57. *Trulla capensis* soon after hatching, lateral and ventral views. NL (alive) = 1,4 mm, NL (fixed) = 1,2 mm. Myomeres: $18 + \text{ca. } 20$.

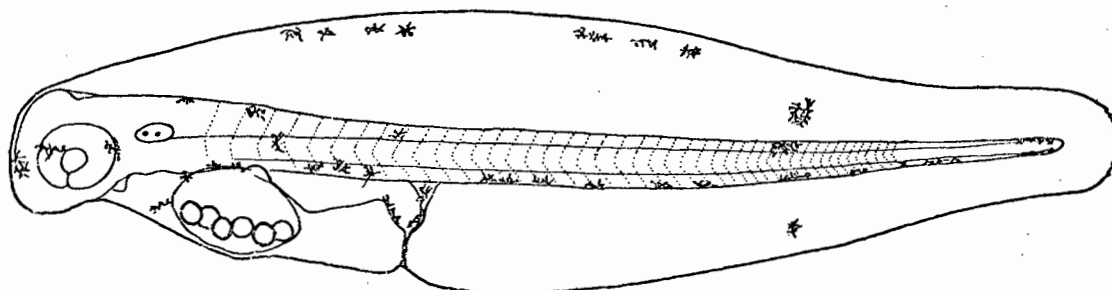


Figure 58. *Trulla capensis* at 2 days (150C). NL (alive) = 2,2 mm, NL (fixed) = 2,0 mm. Myomeres: $10 + 36 = 46$.

4.11 CYNOGLOSSIDAE

Ten cynoglossids were listed from southern African waters by Smith (1975). Only Trulla capensis ranges as far west as the Cape of Good Hope.

4.11.1 Trulla capensis (sand tonguefish) Figs. 56-63.

Previous descriptions of eggs and/or larvae.

Gilchrist & Hunter, 1919 (as Species XXIV): egg, p. 11, fig. 28; larva, p. 11, figs. 29-30.

Egg.

Fig. 56, table 3. The 2-16 oil globules may be clumped or isolated. Most eggs have 4, 6, or 8 globules. They are almost always smaller than Austroglossus microlepis eggs, the only species collected during this study that might cause confusion.

Larva.

Figs. 57-62, table 3. The oil globules in newly-hatched larvae are occasionally clumped in the posterior end of the yolk sac, simulating the situation in Austroglossus microlepis. T. capensis soon becomes more elongate than A. microlepis. The position of the anus distinguishes early larvae of T. capensis from those of Arnoglossus capensis.

Meristics.

D 110-130, A 85-110 (Smith, 1965). Vertebrae: 50-51 (this study).

Geographic and seasonal distribution.

T. capensis is endemic to southern Africa and ranges from (at least) Walvis Bay to Delagoa Bay (Day et al., 1970). The eggs are present, sometimes abundant, on both sides of the Cape Peninsula throughout the year (table 1).

Bearing notes.

Incubation time (15°C): 62 ± 10 h (fig. 185.12). Feeding incidence at first-feeding was nil in several experiments where only Brachionus was offered. The mouth of the larva at this stage is quite small; the maximum allowable size of a food particle seems to be about 100-120 μ m. Proales is a satisfactory food during the first week following yolk absorption. Age-at-optimal-first-feeding is about 165 h post-hatch (Part 1 of this thesis).

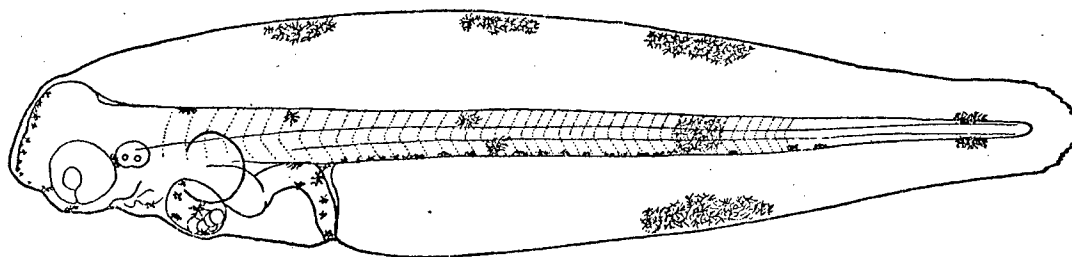


Figure 59. *Trulla capensis* at 4 days (15°C). NL (alive) = 3,0 mm, NL (fixed) = 2,5 mm. Myomeres: 10 + 36 = 46.

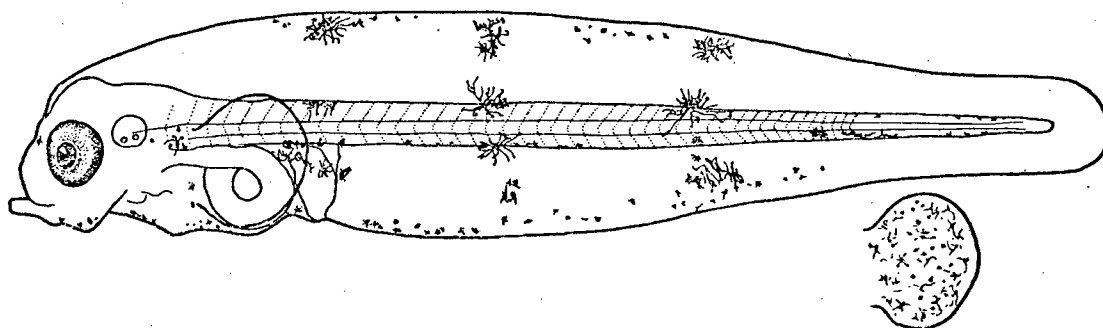


Figure 60. *Trulla capensis* at 8 days (15°C), lateral view and fin detail. NL (alive) = 3,0 mm, NL (fixed) = 2,7 mm. Myomeres: 9 + 35 = 44.

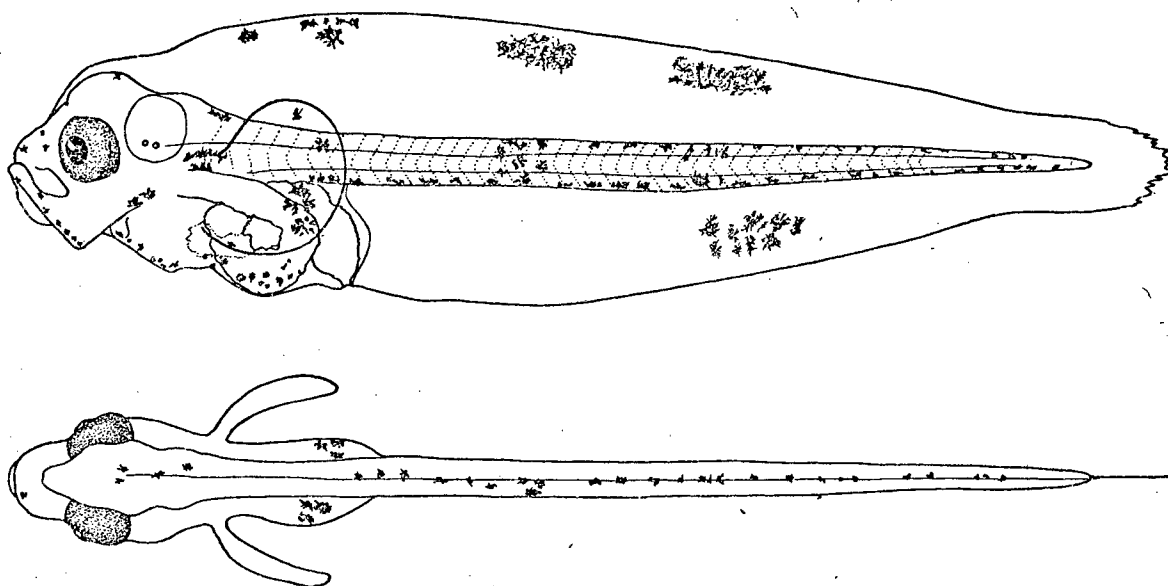


Figure 61. *Trulla capensis* at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,8 mm, NL (fixed) = 3,1 mm. Myomeres: 8 + 36 = 44.

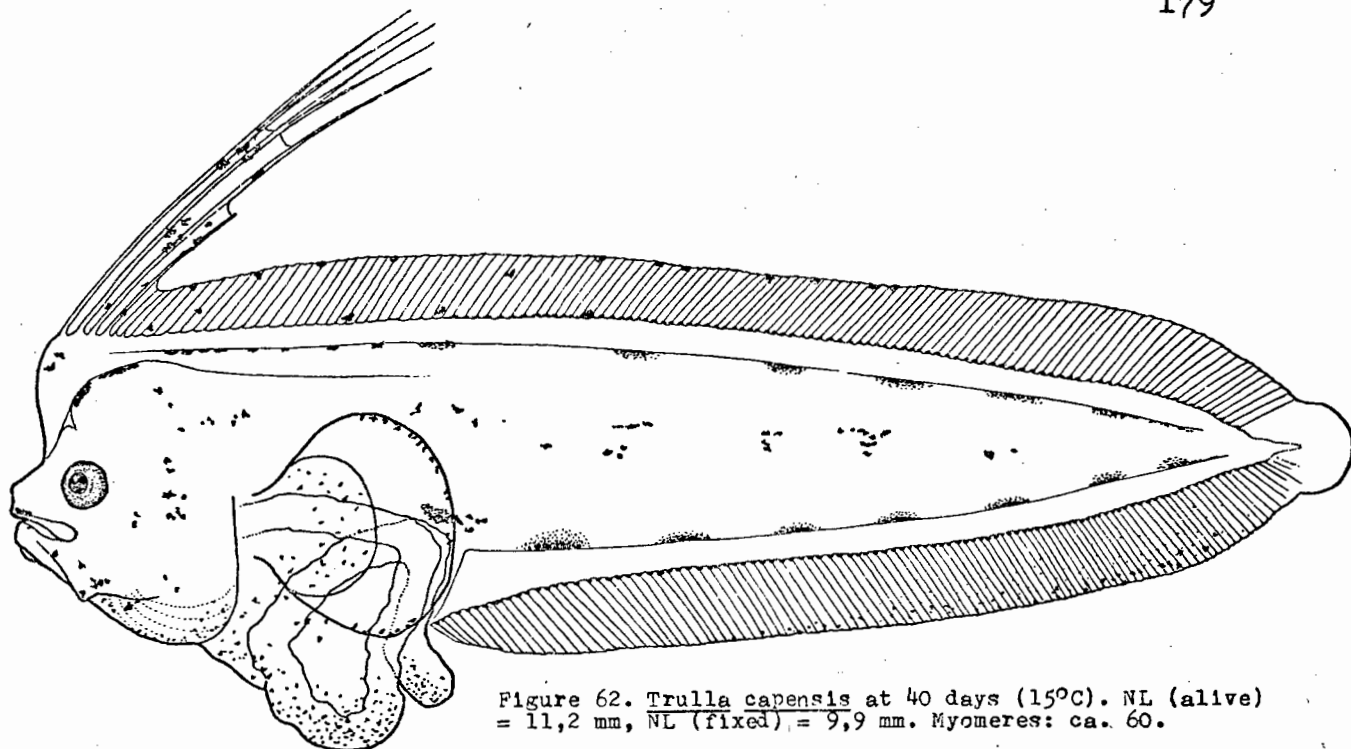


Figure 62. *Trulla capensis* at 40 days (15°C). NL (alive) = 11,2 mm, NL (fixed) = 9,9 mm. Myomeres: ca. 60.

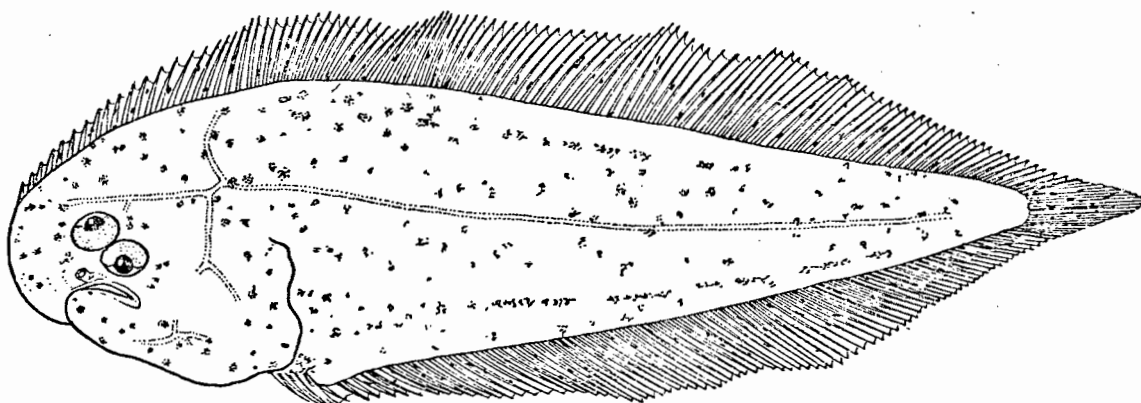


Figure 63. *Trulla capensis* at 60 days (15°C). SL (alive) = 14,8 mm, SL (fixed) = 14,4 mm. D 110, A 87, C 10, Vertebrae: 51.

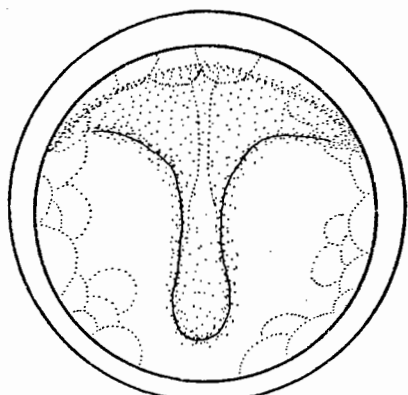


Figure 64. *Paracallionymus costatus* egg. 0,80 mm in diameter.

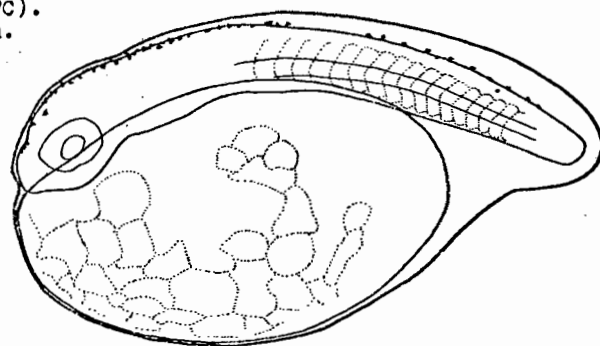


Figure 65. *Paracallionymus costatus* soon after hatching. NL (alive) = 1,05 mm, NL (fixed) = 0,98 mm. Myomeres: 18.

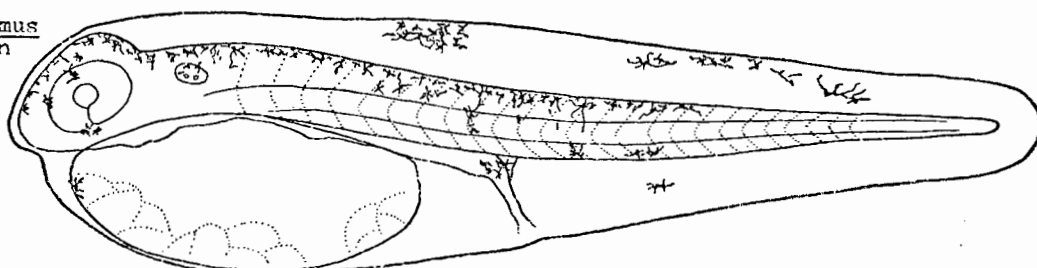


Figure 66. *Paracallionymus costatus* at 2 days (15°C). NL (alive) = 2,1 mm, NL (fixed) = 1,8 mm. Myomeres: 11 + 15 = 26.

The characteristic elongate first dorsal rays become noticeable after about 20 days (15°C). Some larvae elaborated only two such rays prior to metamorphosis, others up to four. It was interesting that, in all cases, metamorphosis occurred over a single night: the prolonged rays degenerated, the right eye migrated to its final sinistral position, and the newly-metamorphosed tonguefish was found in the sand in the morning. Standard lengths at metamorphosis ranged from 1,0 to 1,5 cm. A juvenile kept in an aquarium tank (15°C) and fed primarily on cultured ostracods (Cypridopsis sensu lato) and amphipods (Austrochiltonia subtenuis) grew slowly: at 3,5 months post-hatch, it measured 3,7 cm (TL); at 10 months it measured 5,5 cm (TL).

4.12 CALLIONYMIDAE

The family is represented by a single species in the waters of the Cape Peninsula.

4.12.1 Paracallionymus costatus (ladder dragonet) Figs. 64-68.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904 (as Species XVIII): egg, p. 143; larva, p. 143, figs. 47-48.

Gilchrist & Hunter, 1919 (as Species XVIII): egg, p. 10, fig. 23; larva, p. 10, fig. 24.

Egg.

Fig. 64, table 3. The combination of small size and lack of an oil globule makes the egg unique among those encountered in this study. None of the surface markings that adorn the eggs of some other callionymid species (Russell, 1976:282) is present. The yolk is weakly segmented and slightly cloudy.

Larva.

Figs. 65-68, table 3. Gilchrist & Hunter (1919) called attention to the relatively undeveloped state at hatching (see fig. 65). Larvae at first-feeding are proportioned very similarly to Gaidropsarus capensis larvae at the same age (compare figs. 68 and 9), but fundamental differences (position of anus, myomere count, pigmentation) distinguish

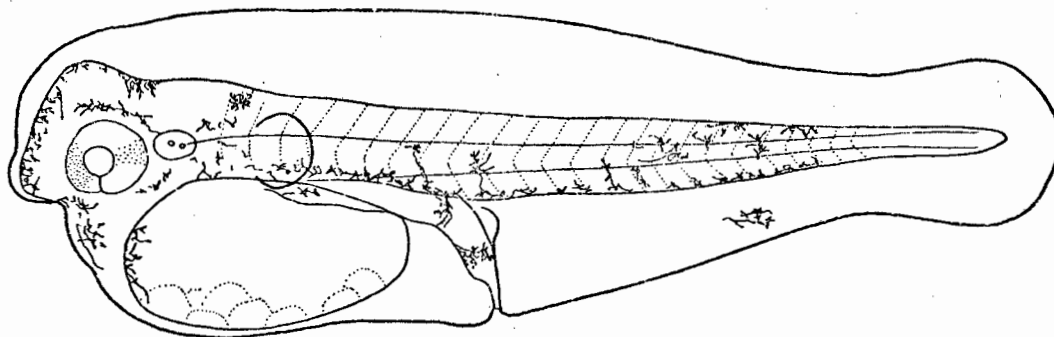


Figure 67. *Paracallionymus costatus* at 4 days (15°C). NL (alive) = 2,2 mm, NL (fixed) = 1,9 mm. Myomeres: 10 + 15 = 25.

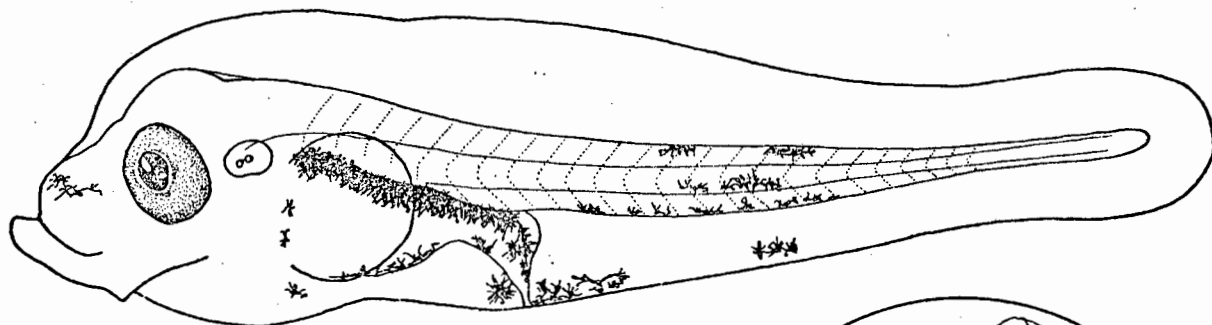


Figure 68. *Paracallionymus costatus* at 8 days (15°C). NL (alive) = 2,3 mm, NL (fixed) unavailable, specimen damaged prior to fixing. Myomeres: 9 + 16 = 25.

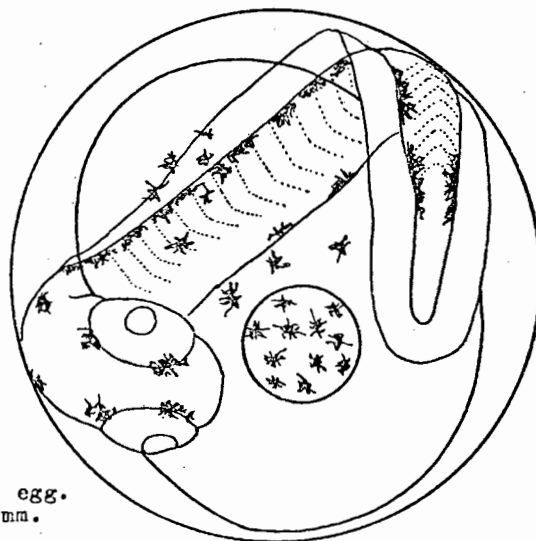


Figure 69. Species 3 (?*Cheilodactylus*) egg. 1,02 mm in diameter, oil globule 0,23 mm.

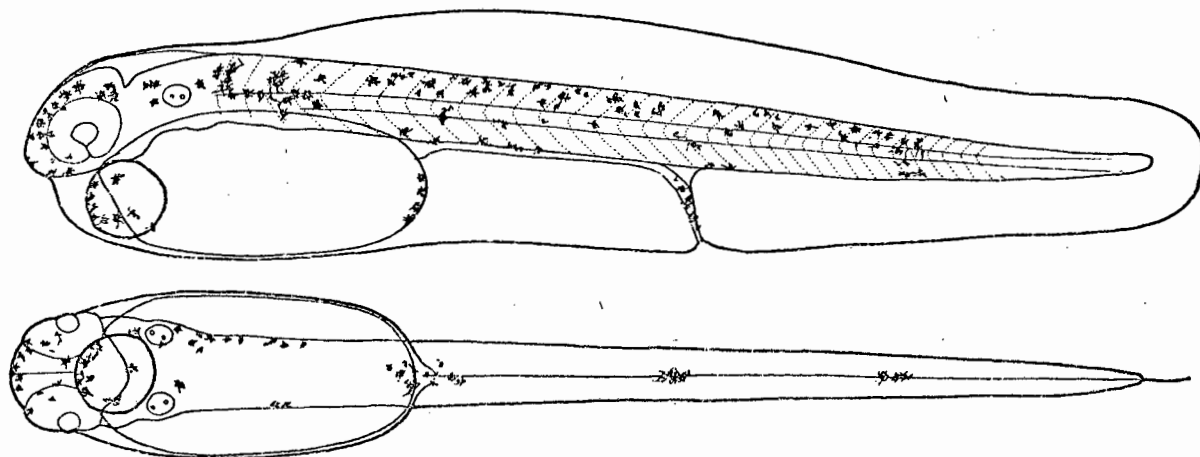


Figure 70. Species 3 (?*Cheilodactylus*) soon after hatching, lateral and ventral views. NL (alive) = 3,6 mm, NL (fixed) = 3,3 mm. Myomeres: 19 + 17 = 36.

them. Older larvae are large-bodied and somewhat dorso-ventrally depressed.

Meristics.

D IV + 9-10, A 9 (Smith, 1965). P 20, Vertebrae: 6 + 15 = 21 (n=1) (this study).

Geographic and seasonal distribution.

P. costatus ranges from St. Helena Bay to Durban (Smith, 1965). During the present study, eggs were taken in Hout Bay and off Three Anchor Bay from March to November, inclusive. None were taken in False Bay collections, although Gilchrist (1904) netted them there, and Day et al. (1970) recorded the presence of the adult. Gilchrist & Hunter (1919) found eggs in Table Bay from September to January. It appears there is year-round spawning in these waters, with possibly two peaks: March/April and September/October/November.

Bearing notes.

This species has the shortest incubation time of all those studied: 40 ± 10 h at 15°C (fig. 185.13). Brachionus and Proales were both taken at first-feeding, though only sporadically. Bearing attempts were unsuccessful. A single larva of about 5 mm SL taken alive at sea was kept in captivity for 8 months, during which time it grew to 5.0 cm SL. It was this specimen that supplied the vertebral count reported above.

4.13 CHEILODACTYLIDAE

The most recent checklist of South African fishes (Smith, 1975) recorded 5 cheilodactylid species, two of which remain unnamed. Four species are possibly represented in Cape of Good Hope waters: Cheilodactylus fasciatus, Chirodactylus brachydactylus, Chirodactylus grandis, and Cheilodactylus sp.

Published accounts of cheilodactylid eggs are limited to Robertson's (1975) descriptions of two New Zealand species (Cheilodactylus macropterus, C. douglasi). Late larvae and pre-juveniles (the laterally-compressed, pelagic phase, sometimes termed "post-larva" (Vooren, 1972; Tong & Saito,

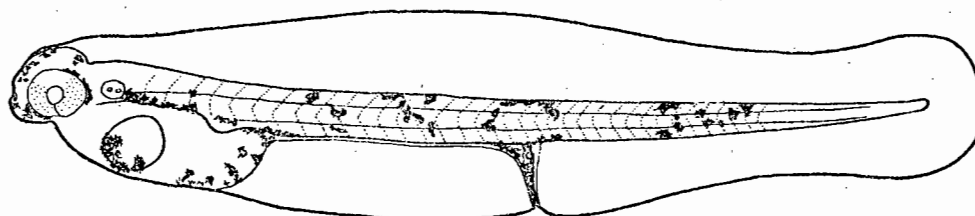


Figure 71. Species 3 (?Cheilodactylus) at 2 days (15°C). NL (alive) = 3,9 mm, NL (fixed) = 3,8 mm. Myomeres: 19 + 17 = 36.

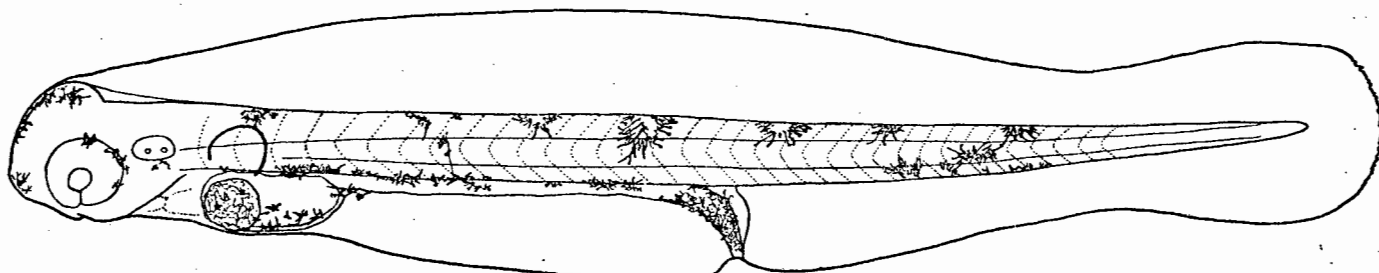


Figure 72. Species 3 (?Cheilodactylus) at 4 days (15°C). NL (alive) = 4,2 mm, NL (fixed) = 3,9 mm. Myomeres: 19 + 17 = 36.

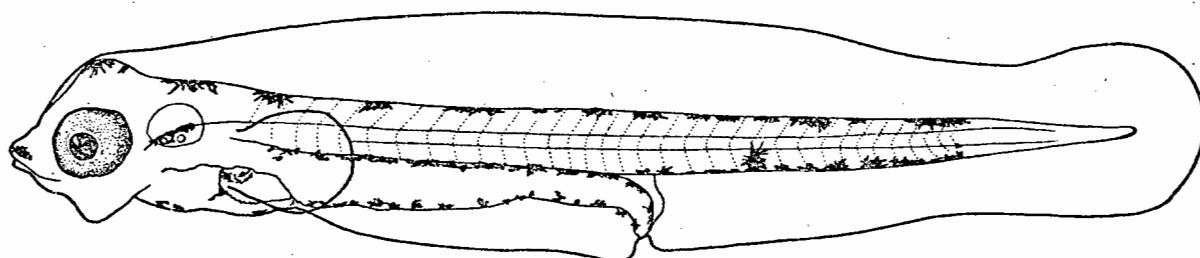


Figure 73. Species 3 (?Cheilodactylus) at 8 days (15°C). NL (alive) = 4,3 mm, NL (fixed) = 4,0 mm. Myomeres: 18 + 17 = 35.

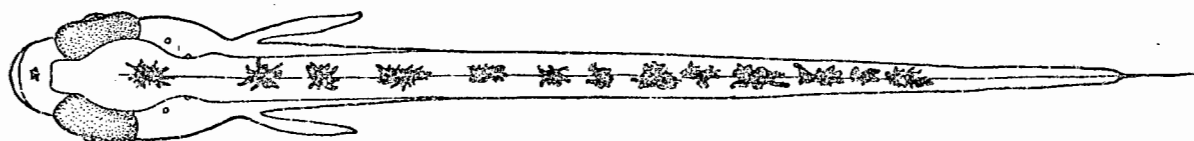
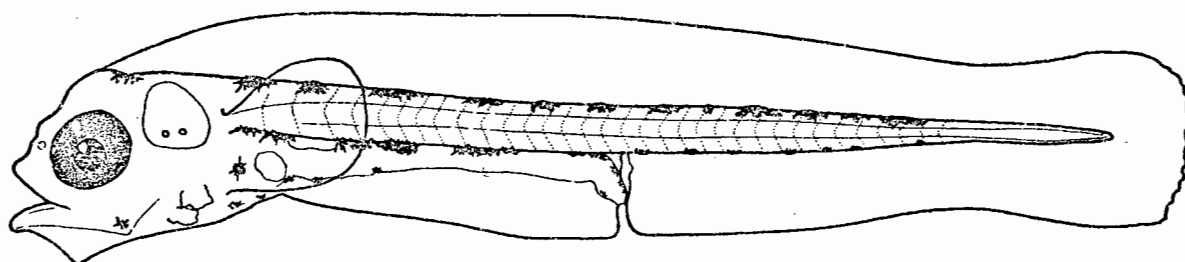


Figure 74. Species 3 (?Cheilodactylus) at 16 days (15°C), lateral and dorsal views. NL (alive) = 4,4 mm, NL (fixed) = 4,1 mm. Myomeres: 18 + 17 = 35.

1977)) of four species were described by Dudnik (1977: Cheilodactylus fasciatus, C. bergi, Cheilodactylus sp., and Chirodactylus brachydactylus). Barnard (1925-1927) and Smith (1965) have also described or figured pre-juveniles of South African cheilodactylids.

4.13.1 Species 3 (?Cheilodactylus fasciatus) Figs. 69-76.

Previous descriptions of eggs and/or larvae.

Gilchrist & Hunter, 1919 (as Species XXIII): egg, p. 11, fig. 25; larva, p. 11, figs. 26-27.

?Barnard, 1925-1927: pre-juvenile, p. 455, fig. 19c.

?Dudnik, 1977: larva, fig. 2; pre-juvenile, fig. 3c.

Notes on identification.

It is with hesitation that the material described below is identified as Cheilodactylus fasciatus. The grounds for choosing this species over the other most likely candidate (Chirodactylus brachydactylus) are not substantial, and there is even a possibility that the eggs of both species are being confused here as one. The oldest larvae reared in this study (about 45 days post-hatch) bear almost as much resemblance to Dudnik's (1977) youngest brachydactylus (his fig. 4) as to his youngest fasciatus (his fig. 2). Neither of his figures show the amount of black pigment over the sub-orbital portion of the preoperculum that is present in the reared material. The oldest reared larvae had not yet elaborated fin elements and the clear-cut difference in dorsal soft-ray counts between the two species does therefore not aid in their identification.

Egg.

Fig. 69, table 3. The advanced embryo has about a dozen melanophores on the oil globule and several on the dorsal surface of the yolk sac on either side of the trunk. The latter often disappear by the time the egg hatches. The anterior position of the oil globule in the yolk is diagnostic in embryos very near hatching. On account of

size overlap between this and other species, early egg stages are difficult (if not impossible) to identify with certainty.

Larva.

Figs. 70-76, table 3. The anterior position of the oil globule and rather posterior position of the anus, the homogeneous yolk, the myomere count, and the characteristic pigmentation effectively distinguish the yolk-sac larva from any of the other species described here. The "upward bend of the anterior portion of the body" noticed by Gilchrist & Hunter (1919:11) on the fourth day post-hatch was an abnormality not observed in the present material.

Meristics.

Pre-juvenile Cheilodactylus fasciatus were reported by Dudnik (1977) to have the following counts: D XVIII - XIX + 20-23, A II + 12-13, P 14, Vertebrae: 34-36. The same author reported these counts for Chirodactylus brachydactylus (n=1): D XVIII + 29, A II + 11, P 14, Vertebrae: 35.

Geographic and seasonal distribution.

C. fasciatus ranges from Port Nolloth to Durban, C. brachydactylus ranges from Walvis Bay to Durban (Day et al., 1970). The eggs were collected on both sides of the Cape Peninsula from February to September, inclusive. A single egg of what appeared to be the same species was taken in False Bay in November (table 1). Gilchrist & Hunter netted the eggs in large numbers in Table Bay in January, March, August and September.

Rearing notes.

Despite numerous attempts, rearing through metamorphosis was unsuccessful. Although first-feeding on Brachionus in the 10-liter rearing tanks was excellent, and the percent survival to about 25 days sometimes exceeded 25%, mortality was consistently total over the subsequent three weeks.

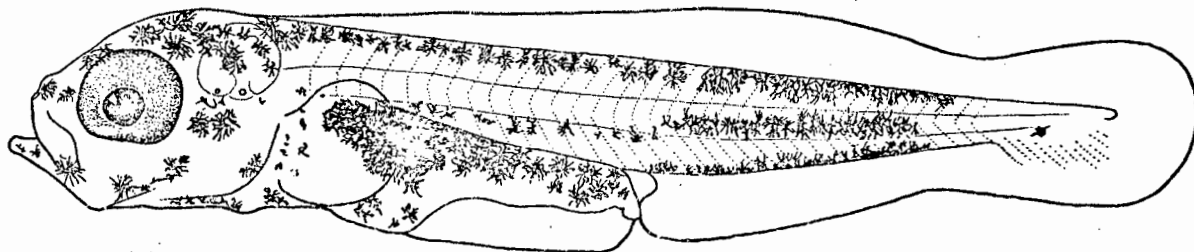


Figure 75. Species 3 (?*Cheilodactylus*) at 32 days (15°C). NL (alive) = 6,9 mm, NL (fixed) = 6,4 mm. Myomeres: 17 + 18 = 35.

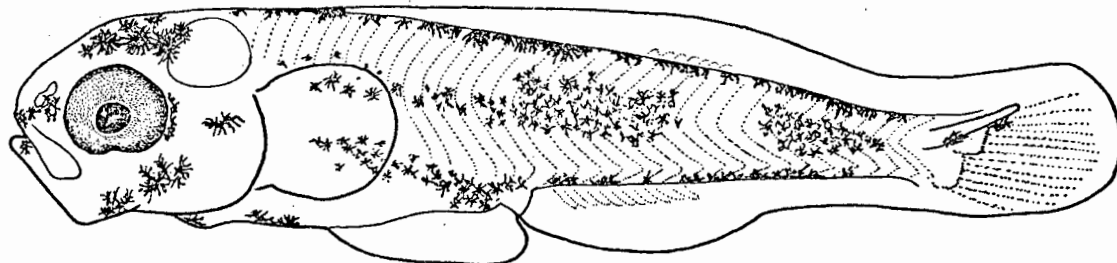


Figure 76. Species 3 (?*Cheilodactylus*) at 45 days (15°C). NL (alive) = 8,0 mm, NL (fixed) = 7,5 mm. Myomeres: 18 + 18 = 36.

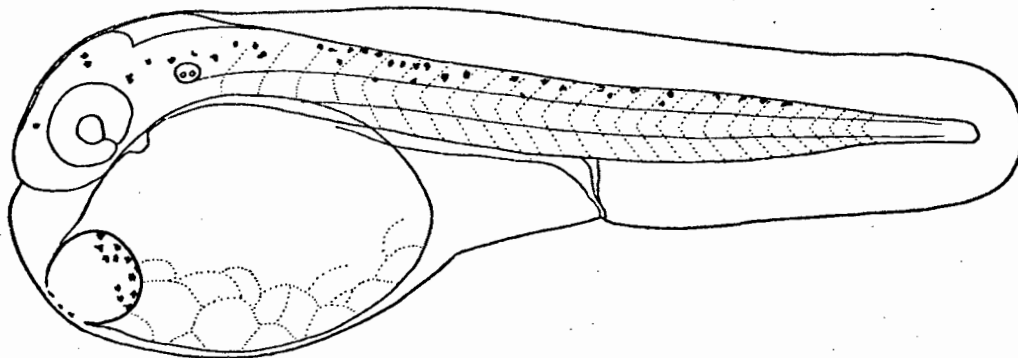


Figure 77. *Trachurus capensis* soon after hatching, lateral and ventral views. NL (alive) = 2,3 mm, NL (fixed) = 2,2 mm. Myomeres: 14 + 14 = 28.

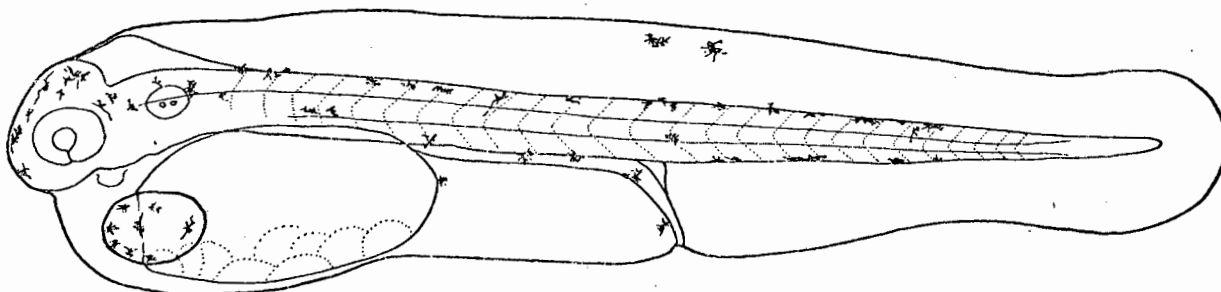
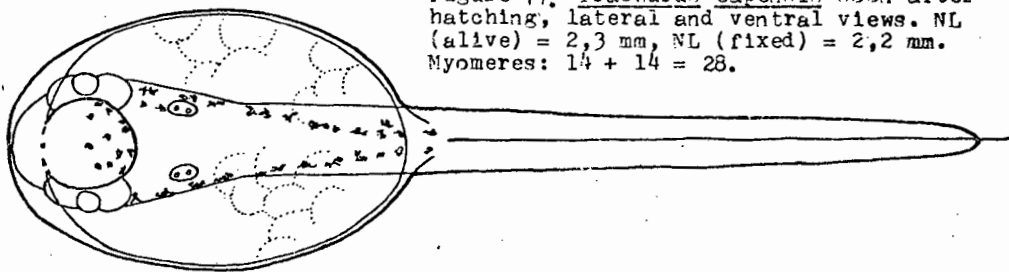


Figure 78. *Trachurus capensis* at 2 days (15°C). NL (alive) = 3,00 mm, NL (fixed) = 2,8 mm. Myomeres: 14 + 13 = 27.

Incubation time (15°C): 86 ± 10 h (fig. 185.14) First-feeding appears to be optimal between 160 and 200 h post-hatch.

4.14 CARANGIDAE

Day et al. (1970) listed seven carangids from False Bay, four of which range into the Atlantic. Some information has been published on the early stages of all of these species (references for five of them, Alectes ciliaris, Decapterus macrosoma, Elagatis bipinnulatus, Lichia amia, and Naukrates ductor, were provided by Aboussouan (1975). References for the other two, Seriola lalandi and Trachurus, are provided below.

4.14.1 Trachurus capensis (maasbanker) Figs. 77-81.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Species VI): egg, p. 198; larva, p. 198, fig. 28.

not Gilchrist, 1916 (as Caranx trachurus): egg, p. 9; larva, p. 9, fig. 5. (Gilchrist described another carangid species here—the one treated below as ?Seriola.)

Haigh, 1972b (as Trachurus trachurus): egg, p. 140; larva, p. 141, figs. 1-3.

King et al., 1977 (as Trachurus trachurus): egg, p. 17, fig. 2; larva, p. 18, fig. 4.

Egg.

Table 3. Maasbanker eggs cannot be separated from those of a number of other species (particularly sparids) on the basis of size alone. They can be distinguished by virtue of the combination of yolk vesiculation and chorion and oil globule dimensions. The reader should refer to King et al. (1977) for figures and a more detailed description of the egg and early larva.

Larva.

Figs. 77-81, table 3.

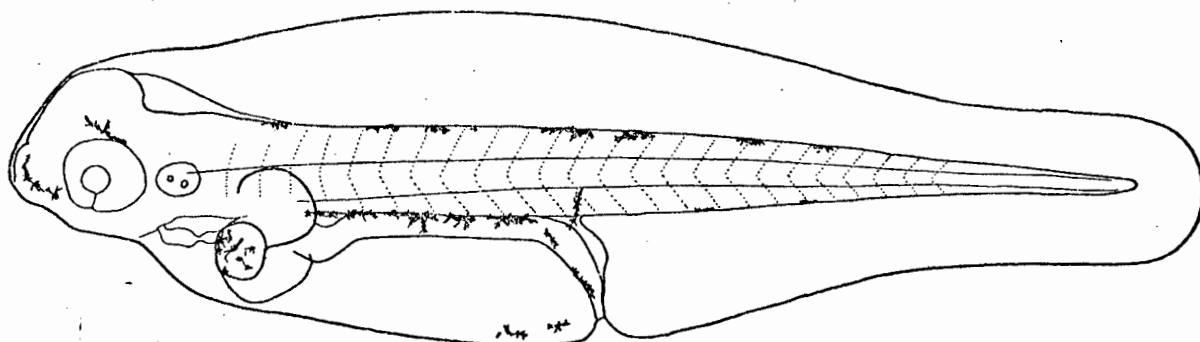


Figure 79. *Trachurus capensis* at 4 days (15°C). NL (alive) = 3,6 mm, NL (fixed) = 2,9 mm. Myomeres: 13 + 12 = 25.

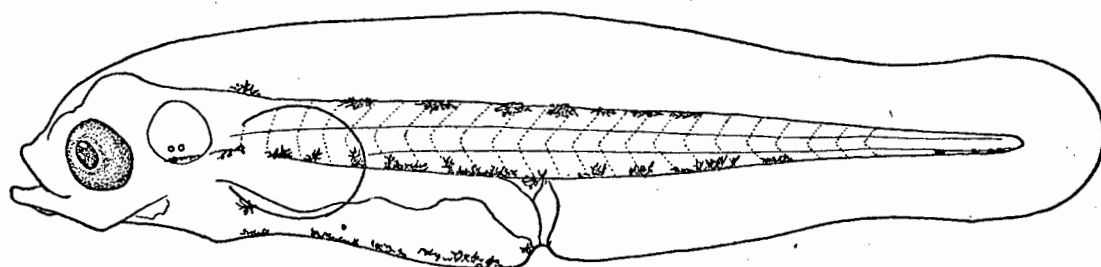


Figure 80. *Trachurus capensis* at 8 days (15°C). NL (alive) = 3,7 mm, NL (fixed) = 3,6 mm. Myomeres: 12 + 12 = 24.

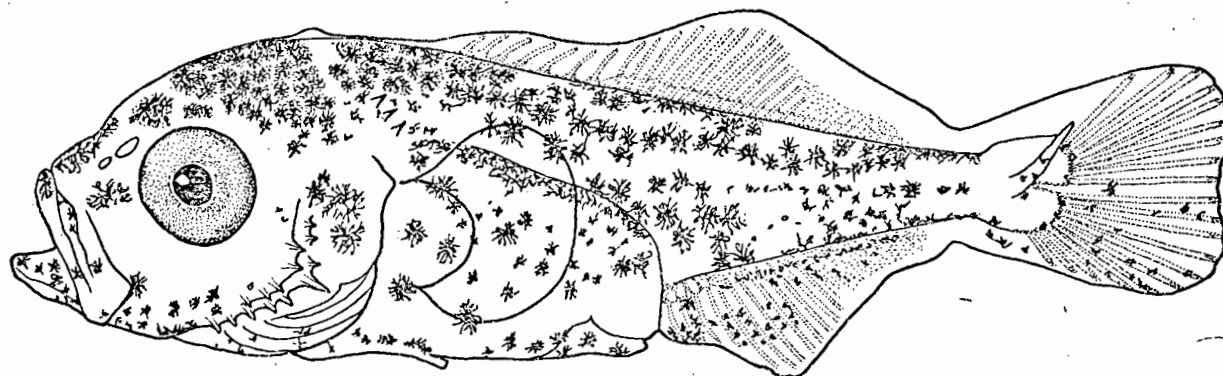


Figure 81. *Trachurus capensis* at 32 days (15°C). SL (alive) = 9,5 mm, SL (fixed) = 8,9 mm. Fin elements have not yet reached definitive counts.

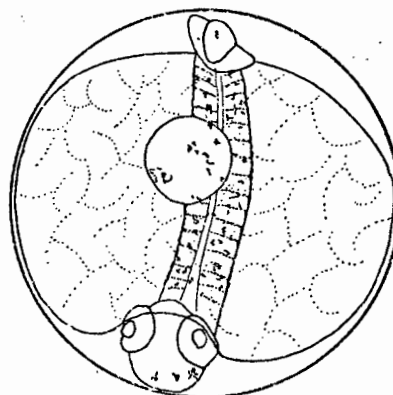


Figure 82. Species 4 (?*Seriola*) egg. 1,44 mm in diameter, oil globule 0,32 mm.

Meristics.

D VIII + I + 30-34, A II + I + 27-29, P 22, Vertebrae: 10 + 14 = 24 (Haigh, 1972b, table 1: juveniles).

Geographic and seasonal distribution.

Following the nomenclature of Smith (1975), the South African maasbanker is regarded here as distinct from the European horse mackerel, Trachurus trachurus. The limits of its distribution northward into the eastern Atlantic have apparently not yet been established. T. capensis ranges eastward to Delagoa Bay (Smith, 1965). Maasbanker eggs appeared sporadically in the plankton hauls made during this study (table 1), and no trends are evident. Published data on reproduction in this species are not entirely in accord. Davies (1957) and Geldenhuys (1973) argued for a spawning season of late winter and spring. Komarov (1964) reported year-round, asynchronous spawning in Namibian waters, but his data concerned only the months November to May, inclusive, and July. King et al. (1977) collected maasbanker eggs in False Bay in March; Gilchrist (1903) took the eggs in False Bay in December.

Rearing notes.

Incubation time at 15°C is estimated to be 56 ± 10 h (fig. 185.15). This value is in close agreement with the results of King et al. (1977, fig. 3), which indicated an incubation time (actually, blastula to hatching) of about 58 h at 15°C. First-feeding was successful on both Proales and Brachionus. Definitive fin counts were attained at an age of about 6 weeks (15°C). Two 70-day-old juveniles measured 2,5 cm SL.

4.14.2 Species 4 (?Seriola lalandi) (Cape yellowtail) Figs. 82-84.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Species IV): egg, p. 197; larva, p. 197, fig. 26.

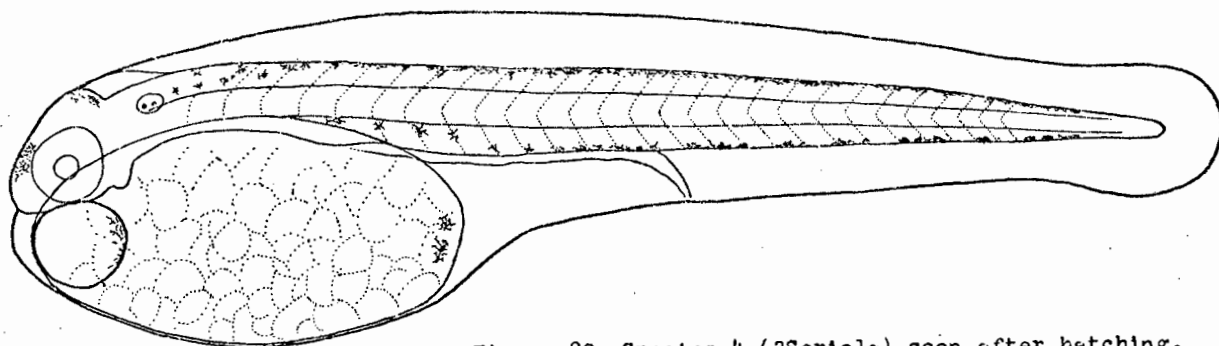


Figure 83. Species 4 (?*Seriola*) soon after hatching, lateral and ventral views. NL (alive) = 4,0 mm, NL (fixed) = 3,3 mm. Myomeres: 15 + 11 = 26.

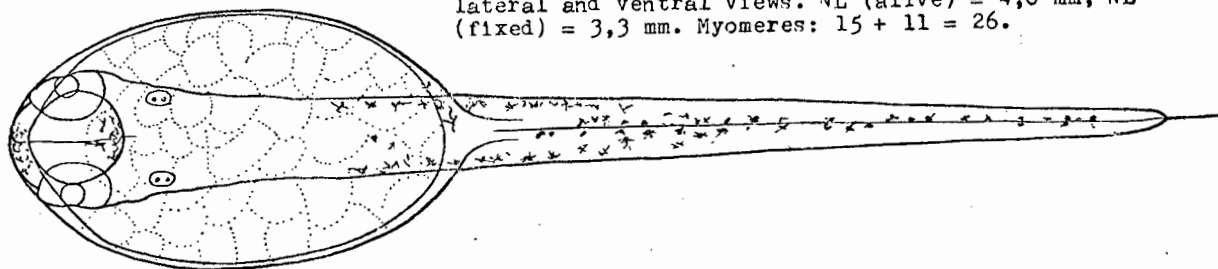


Figure 84. Species 4 (?*Seriola*) at 2 days. NL (alive) = 4,8 mm, NL (fixed) = 4,0 mm. Myomeres: 16 + 11 = 27.

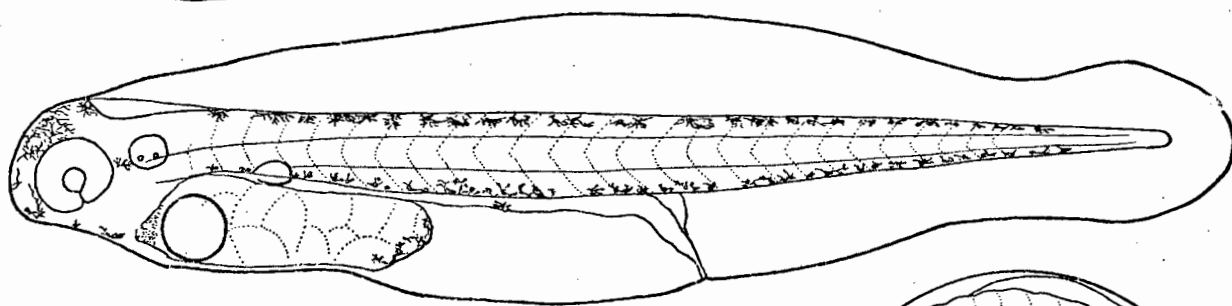


Figure 85. *Pterosmaris axillaris* egg. 1,23 mm in diameter, oil globule 0,26 mm.

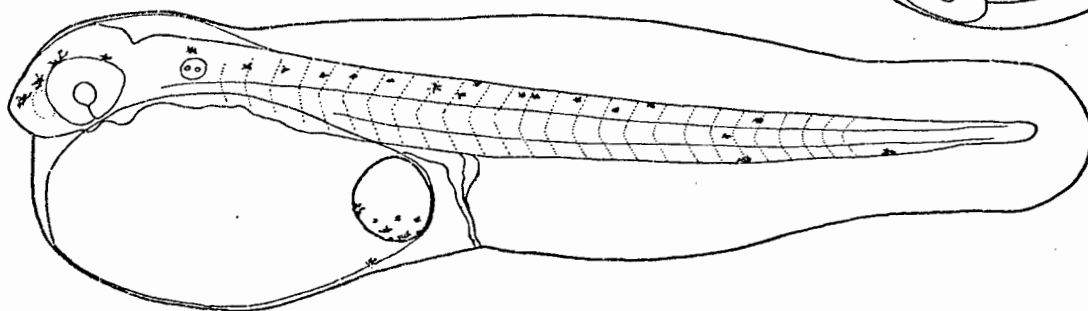
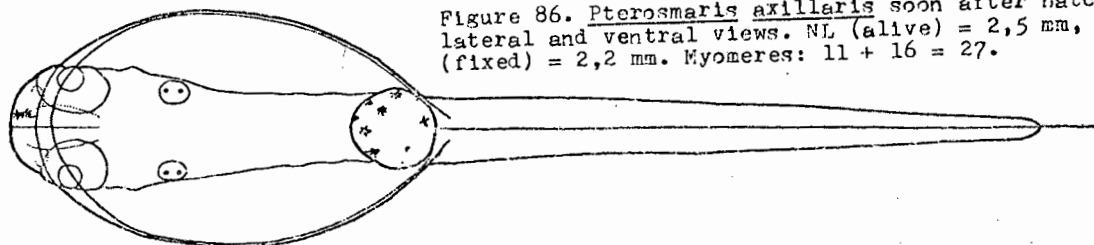


Figure 86. *Pterosmaris axillaris* soon after hatching, lateral and ventral views. NL (alive) = 2,5 mm, NL (fixed) = 2,2 mm. Myomeres: 11 + 16 = 27.



Gilchrist, 1916 (as Caranx trachurus): egg, p. 9; larva, p. 9, fig. 5.

?Gilchrist, 1916 (as Seriola lalandi): ovarian egg, p. 9.

Notes on identification.

The anterior position of the oil globule, the relatively long gut, the vesiculated yolk, the presence of yellow pigmentation on the finfolds, and the myomere count place this species among the Carangidae. Its tentative referral to Seriola lalandi is based on Gilchrist's (1916) description of ripe ovarian eggs of that species (diameter 1,27 mm, with single oil globule 0,34 mm) and on descriptions of eggs and early larvae of other Seriola species. Although the egg of Naucrates ductor, as described by Sanzo (1931b), also has a vesiculated yolk and is of similar size (chorion diameter ca. 1,32 mm, oil globule 0,28 mm), the extent of the black pigmentation, especially on the yolk-sac, effectively removes it from consideration. (As pointed out by Barnard (1926), Gilchrist's (1918) description of Naucrates eggs as oval, bearing a filament, and lacking an oil globule was in error.) To the author's knowledge, eggs and early larvae of the leervis, Lichia amia, have not yet been described, and a definitive identification of the present material as S. lalandi might best be deferred until such time.

Egg.

Fig. 82, table 3.

Larva.

Figs. 83-84, table 3.

Meristics.

Seriola lalandi: D I + VI - VII + I + 32-34, A II + I + 20-25. (Smith, 1965). Lichia amia: D VII + I + 19-21, A II + I + 17-20, P I + 18-20, Vertebrae: 10 + 14 = 24 (Smith-Vaniz & Staiger, 1973).

Geographic and seasonal distribution.

This egg was not taken in the Atlantic; it appeared in small numbers in False Bay collections in November and January (table 1). Gilchrist (1903) collected the egg from False Bay in December; he (1916) procured a ripe female S. lalandi in February. Smith (1959) gave January-March as the spawning period of S. lalandi.

Rearing notes.

Rearing attempts were totally without success. Only one larva reached potential first-feeding age, but was obviously deformed and showed no food-searching behavior. 15°C is probably too cold for the normal development of this species.

4.15 CENTRACANTHIDAE

This small family, closely allied to the Sparidae, is presently thought to consist of seven species (Heemstra & Randall, 1977), of which two (Pterosmaris axillaris and Centracanthus australis) are endemic to South Africa. The most-studied member of the family is probably Spicara smaris, a protogynous hermaphrodite with demersal eggs from the NE Atlantic, Mediterranean, and Black Sea. Its reproductive behavior has been detailed by Salekhova (1969) and Harmelin & Harmelin-Vivien (1976). Pelagic eggs from the Mediterranean were attributed to the centracanthid, Centracanthus cirrus (as Smaris insidiator) by Sanzo (1939), Thomopoulos (1954), and Aboussouan (1964). Those eggs are peculiar in having a single, nipple-shaped protrusion at one point on the chorion (Thomopoulos, 1954, fig. 4). The egg of Pterosmaris axillaris, described below, differs from all previously-described centracanthid eggs in being pelagic and completely spherical.

4.15.1 Pterosmaris axillaris (windtoy) Figs. 85-92.

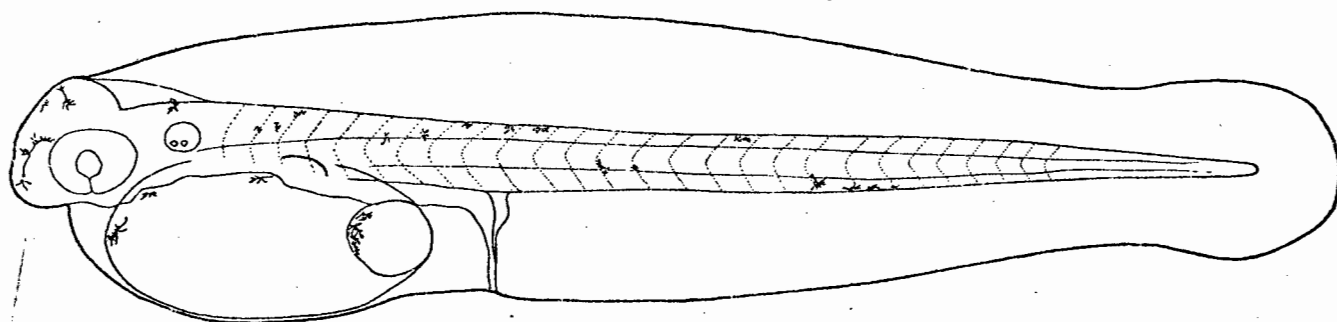


Figure 87. *Pterosmaris axillaris* at 2 days (15°C). NL (alive) = 3,3 mm, NL (fixed) = 3,0 mm. Myomeres: 10 + 17 = 27.

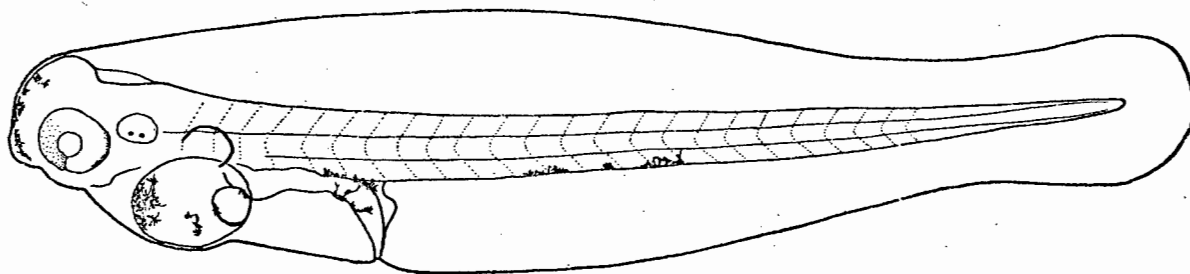


Figure 88. *Pterosmaris axillaris* at 4 days (15°C). NL (alive) = 3,4 mm, NL (fixed) unavailable (specimen lost). Myomeres: 8 + 17 = 25.

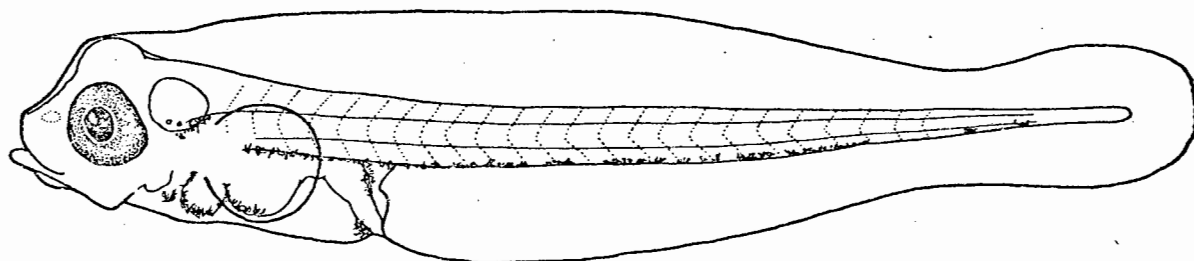


Figure 89. *Pterosmaris axillaris* at 8 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,4 mm. Myomeres: 7 + 18 = 25.

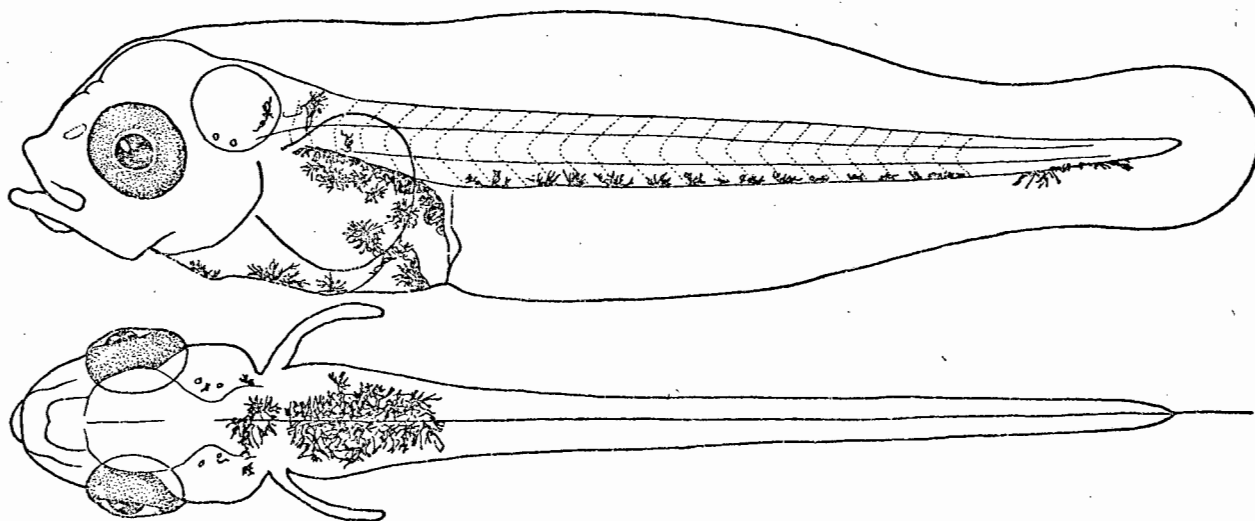


Figure 90. *Pterosmaris axillaris* at 16 days (15°C), lateral and dorsal views. NL (alive) = 5,2 mm, NL (fixed) = 4,8 mm. Myomeres: 7 + 18 = 25.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Fig. 85, table 3. The eggs of P. axillaris were often taken together with eggs of Pachymetopon blochi, from which they are indistinguishable until the embryo is well-formed. The distribution of yellow pigment in the late embryo can be used to separate the two species: P. blochi has xanthophores anterior to the eyes and slightly posterior to the otocysts, Pt. axillaris has neither.

Larva.

Figs. 86-91, table 3. See comments under section 4.16.6 (Pachymetopon blochi) and section 4.16.8 (Species 5).

Meristics.

D XI + 12-13, A III + 11-12 (Smith, 1965). P 17, Vertebrae: 10 + 14 = 24 (this study).

Geographic and seasonal distribution.

P. axillaris ranges from Table Bay to Durban (Day et al., 1970). Its eggs were collected in Table Bay from March to September, inclusive. They were taken less regularly and in smaller numbers in False Bay over roughly the same period (table 1).

Bearing notes.

Incubation time (15°C): 90 ± 10 h (fig. 185.16). Age-at-optimal-first-feeding was estimated (Part 1 of this thesis, fig. 6) at 190 h post-hatch. Larvae first-fed on either Proales or Brachionus. Definitive fin-ray counts were attained at an age (15°C) of 5-6 weeks. The 32-day specimen presented in fig. 91 was slightly smaller than average—probably malnourished.

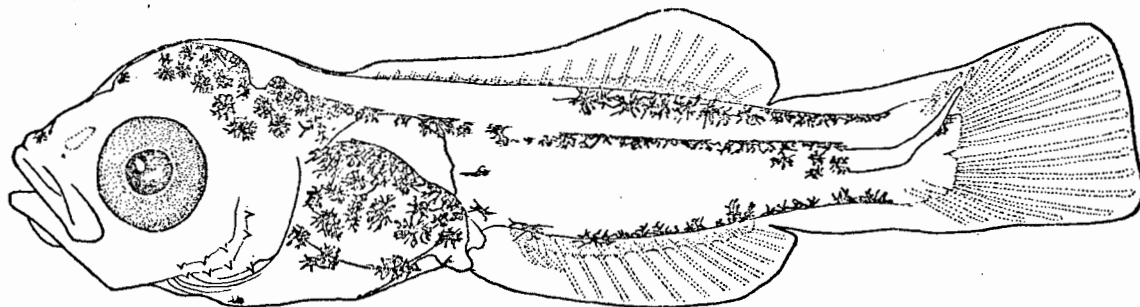


Figure 91. *Pterosmaris axillaris* at 32 days (15°C). SL (alive) = 7,7 mm, SL (fixed) = 7,2 mm. Fin elements have not yet reached definitive counts.

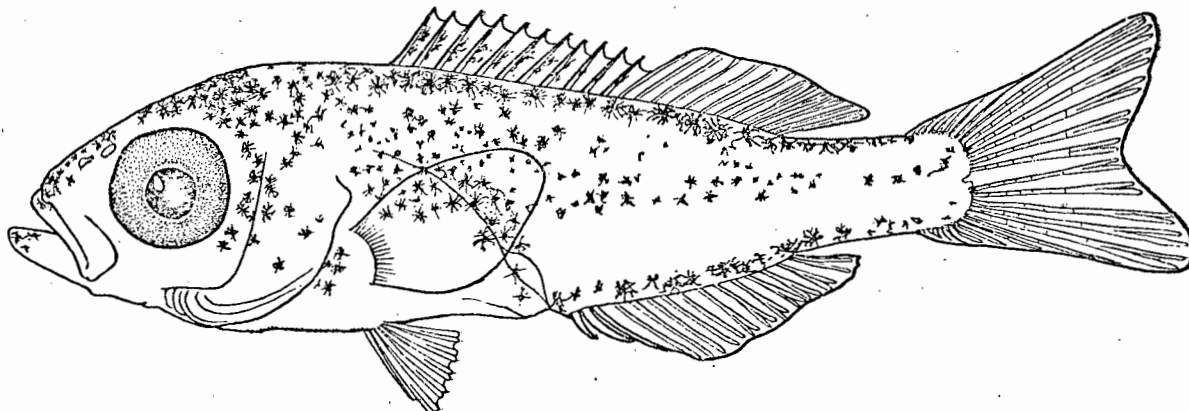


Figure 92. *Pterosmaris axillaris* at 3 months (15°C). SL (alive) = 18,2 mm, SL (fixed) = 16,5 mm. D XI + 13, A III + 12, P 17, Vertebrae: 10 + 14 = 24.

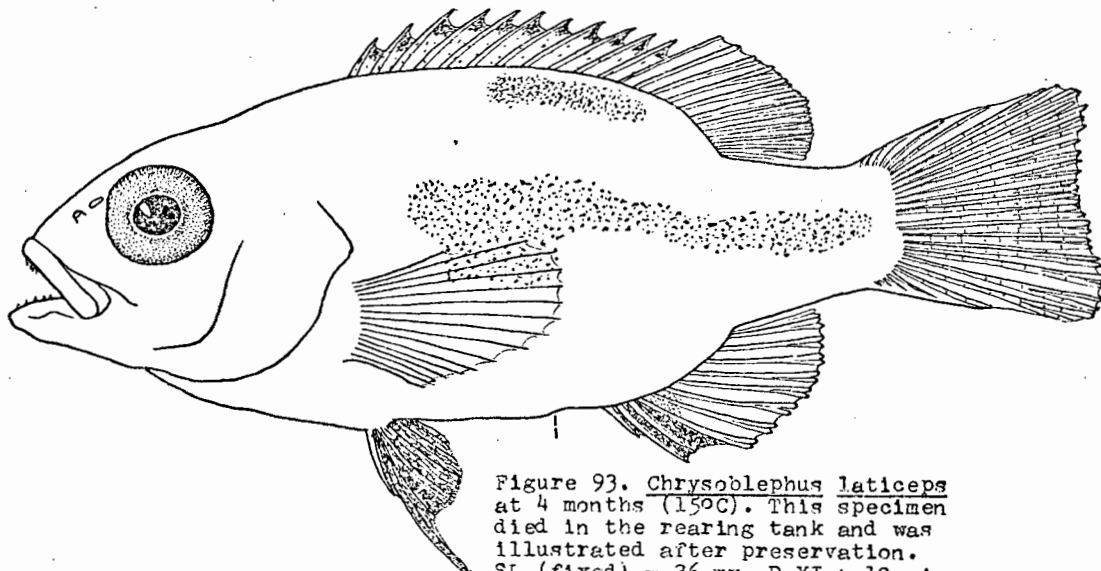


Figure 93. *Chrysoblephus laticeps* at 4 months (15°C). This specimen died in the rearing tank and was illustrated after preservation. SL (fixed) = 36 mm. D XI + 10, A III + 8, P 16.

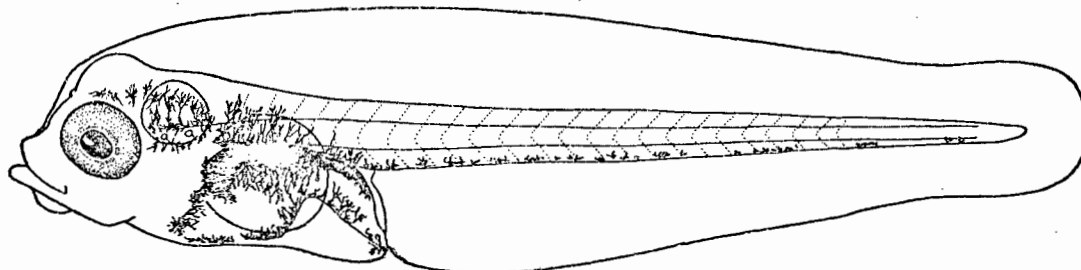


Figure 94. *Diplodus cervinus* at 8 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,3 mm. Myomeres: 7 + 18 = 25.

4.16 SPARIDAE

Smith (1975) listed 41 sparid species in southern African waters. Of those, Day et al. (1970) recorded 22 from False Bay, of which 15 range around the Cape of Good Hope into the Atlantic, at least as far as Table Bay. Since many of the South African sparids are important commercial and sport species, there has been a fair amount of attention paid to their biology, including reproduction. The available information on spawning and development in the 22 Cape of Good Hope sparids is summarized in table 2.

Known eggs of the South African sparid fishes fall into the size range 0,80-1,30 mm in diameter and have a single oil globule 0,16-0,25 mm in diameter. The only species known to have demersal eggs is the steentjie, Spondyllosoma emarginatum. Notes on the breeding behavior of the steentjie in an aquarium were published by Bruggen (1965); no description of the demersal eggs was provided.

The following treatment of early stages of Cape Peninsula sparids is regrettably far from complete. Six species, Diplodus cervinus, D. sargus, Lithognathus mormyrus, Pachymetopon blochi, Chrysoblephus laticeps, and Gymnocrotaphus curvidens, were reared through metamorphosis during this study. The author believes that several other sparid species spawn in these waters, but that a thorough understanding of their early life stages will depend on access to ripe adults, as well as to rearing facilities.

4.16.1 Chrysoblephus laticeps (roman) Fig. 93.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Not recognized.

Table 1. Summary of available reproductive information on the sparids of the Cape of Good Hope. Unless otherwise stated, the spawning seasons listed here apply to populations in waters of the Cape Province.

Species	spawning season	sexual type	life stages described	reference
<u>Argyrozona argyrozona</u> (silverfish)	artificially fertilized ripe adults in December	gonochorism	egg, pre-feeding larva	Gilchrist, 1903, 1916 Nepgen, 1977
<u>Boopsidea inornata</u> (fransmadam)	"spawn mainly in spring and summer months" p.19	gonochorism	juvenile of 6,3 cm	Smith, 1965 Penrith, 1972b
<u>Cheilimerius nufar</u> (santer)	procured ripe eggs in January		ovarian egg	Gilchrist, 1916
	June - September (Gulf of Aden area)		juvenile of 25 cm	Smith, 1965 Druzhinin, 1975
<u>Chrysoblephus cristiceps</u> (dageread)		possible hermaphroditism	juveniles	Smith, 1943, 1965 Penrith, 1972b
<u>Chrysoblephus gibbiceps</u> (red stumpnose)	artificially fertilized ripe adults in November "spawns in midsummer" p. 184		egg, pre-feeding larva	Gilchrist, 1903, 1916 Biden, 1930
<u>Chrysoblephus laticeps</u> (roman)	"mature roe in December" p. 184	gonochorism		Penrith, 1972b Biden, 1930
	ripe-running in December and January in False Bay	protogynous hermaphroditism		Penrith, 1972b Penrith, 1975 (pers. comm.)

Table 2. (continued)

species	spawning season	sexual type	life stages described	reference
<u>Cymatoceps</u> <u>nasutus</u> (poenskop)			juveniles of 15 and 20 cm	Smith, 1965
<u>Diplodus</u> <u>cervinus</u> (zebra)	very probably spawns in midsummer		larva	Biden, 1930
<u>Diplodus</u> <u>sargus</u> (blacktail)	"ripe eggs have been found in the summer months" p. 6 spawning peak in mid- summer; "the great majority of females carry ripe roe at all times of the year" p.200		ovarian egg	(this study) Gilchrist, 1916
				Biden, 1930
<u>Gymnoerotaphus</u> <u>curvidens</u> (janbruin)	procured ripe eggs in September "spawning season is midsummer" p. 230 October - December, inclusive probably spawns in July and August	gonochorism ¹	egg, larva ovarian egg	Penrith, 1972b (this study) Gilchrist, 1916
<u>Lithognathus</u> <u>lithognathus</u> (white steenbras)		simultaneous hermaphroditism	larva, juvenile	Biden, 1930 (this study)
<u>Lithognathus</u> <u>mormyrus</u> (sandsteenbras)	artificially fertilized ripe adults in January	protandrous hermaphroditism	egg, pre-feeding larva	Mehl, 1973
	May to August, inclusive (in the Adriatic)		egg, pre-feeding larva	Gilchrist, 1903, 1916 Lissia-Frau & Casu, 1968 Varagnolo, 1964

footnotes: 1. Lissia-Frau & Pala (1968) presented evidence for protandry in D. sargus. Reinboth (1970), however, discounted it.

Table 1. (continued)

species	spawning season	sexual type	life stages described	reference
<u>Lithognathus</u> <u>mormyrus</u> (cont.)	Middle of May through September (in the wes- tern Mediterranean)	hermaphroditism of a complex type ²		Suau, 1970
<u>Pachymetopon</u> <u>aeneum</u> (blue hottentot)	October to February, inclusive (no reproductive information is available on this species)		egg, larva	(this study)
<u>Pachymetopon</u> <u>blochi</u> (hottentot)	spawning peaks in summer and winter; minor spawning in spring and autumn	gonochorism	ovarian egg	Gilchrist, 1916 Nepgen, 1977
<u>Pachymetopon</u> <u>grande</u> (bronze bream)	January to August, inclusive (eggs very rare during rest of the year)		egg, larva	(this study)
<u>Petrus</u> <u>rupestris</u> (cristie)		gonochorism	juvenile of 23 cm	Penrith, 1972b Smith, 1965
<u>Polysteganus</u> <u>undulosus</u> (seventyfour)	July through November (in Natal)	gonochorism	juveniles	Penrith, 1972b Ahrens, 1965 Smith, 1943, 1965 Penrith, 1972b

Footnotes: 2. Suau (1970: western Mediterranean) found evidence of both protandrous and protogynous sex inversion: the former was encountered most frequently during the spawning season, the latter in January. During the three months prior to spawning, he found only gonochorists; during the period September-December, he detected no well-defined tendency toward any sexual type.

Table 2. (continued)

species	spawning season	sexual type	life stages described	reference
<u>Pterogymnus</u> <u>lanianus</u> (paria)	procured ripe eggs in March and June probably spawns all year with peaks in January-February and September	gonochorism ? ³	ovarian egg	Gilchrist, 1904, 1916 Budnichenko & Dimitrova, 1970 Penrith, 1972b Hecht & Baird, 1977
<u>Rhabdosargus</u> <u>globiceps</u> (white stump-nose)	mid-September to May procured ripe eggs in November and December spawning peak in mid-summer; minor spawning the rest of the year p. 184 procured fully-ripe females in August; probably spawns from August to about February	gonochorism protogynous hermaphroditism	egg, pre-feeding larva	Gilchrist, 1903, 1916 Biden, 1930 Talbot, 1955
<u>Sarpa salpa</u> (strepie)	September - October (in western Mediterranean)	gonochorism		Penrith, 1972b
<u>Sparodon</u> <u>durbanensis</u> (musselcracker)		hermaphroditism of a complex type ⁴	juvenile	Malo-Michèle, 1977 Smith, 1965
<u>Spondyllosoma</u> <u>emarginatum</u> (steentjie)	nest-building and spawning activity observed in the Port Elizabeth aquarium, September to middle of November breeding behavior seen in False Bay in January		(has demersal eggs)	Bruggen, 1965
		gonochorism ⁵		Penrith, 1972a Penrith, 1972b

footnotes: 3. Budnichenko & Dimitrova (1970) examined the gonad histology of 56 specimens and apparently did not detect any departure from gonochorism. Their published data, however, are not inconsistent with a hypothesis (see Hecht & Baird, 1977) of protogynous hermaphroditism.

4. Juveniles up to an age of four years are "rudimentary", or "potential" hermaphrodites; thereafter, they may become functional females or functional males, or first functional males and then functional females (Malo-Michèle, 1977)

5. The European Spondyllosoma cantharus, however, is known to be a protogynous hermaphrodite (Reinboth, 1970:524, 527).

Larva.

Two Chrysoblephus laticeps and one unidentified Chrysoblephus species were reared through metamorphosis during this study. They hatched from eggs originally identified as Diplodus sargus, and were only recognized as unique as metamorphosis approached. Early juveniles were characterized by a prolonged first ventral soft ray and concentrations of melanophores at the following places: 1) spinous dorsal, 2) spinous anal, 3) ventral fins, 4) center of operculum, and 5) the two longitudinal patches stippled in fig. 93.

Meristics.

D XI-XII + 10-11, A III + 7-9 (Smith, 1965). P 16, Vertebrae: 10 + 14 = 24 (this study).

Geographic and seasonal distribution.

According to Day et al. (1970), the roman is endemic to South Africa, with a distribution from Table Bay to Natal. Available data (tables 1-2) indicate a spring/summer spawning season.

Bearing notes.

An individual kept for 8 months after hatching (then died as a result of an aeration malfunction) reached a total length of 6,6 cm (SL = 5,5 cm) (15°C).

4.16.2 Diplodus cervinus (zebra) Figs. 94-96.

Previous descriptions of eggs and/or larvae.

None (juvenile stage figured by Smith & Smith (1966)).

Egg.

Table 3. The egg and prefeeding larva of D. cervinus were only recognized at the very end of this study and time did not permit proper illustration. Although the average diameter of D. cervinus eggs appears to exceed the average diameter of D. sargus eggs, the overlap in their size

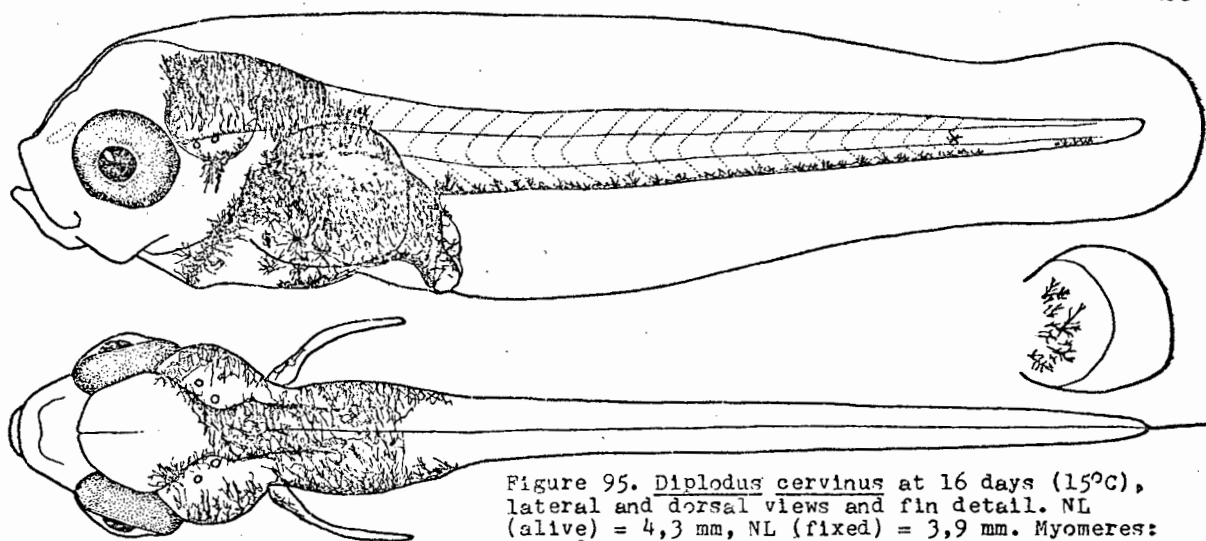


Figure 95. Diplodus cervinus at 16 days (15°C), lateral and dorsal views and fin detail. NL (alive) = 4,3 mm, NL (fixed) = 3,9 mm. Myomeres: 7 + 18 = 25.

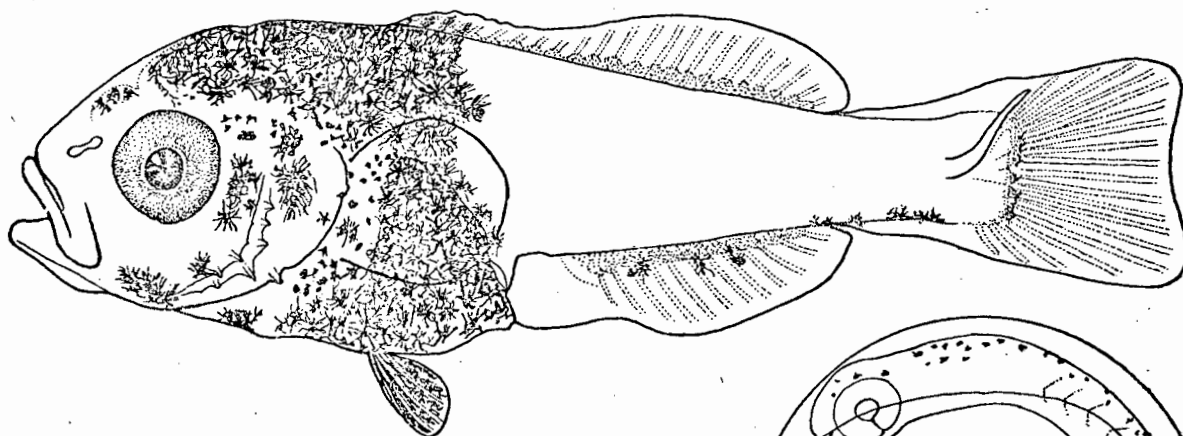


Figure 96. Diplodus cervinus at 32 days (15°C). SL (alive) = 7,9 mm, SL (fixed) = 7,4 mm. Fin elements have not yet reached definitive counts.

Figure 97. Diplodus sargus egg. 0,94 mm in diameter, oil globule 0,20 mm.

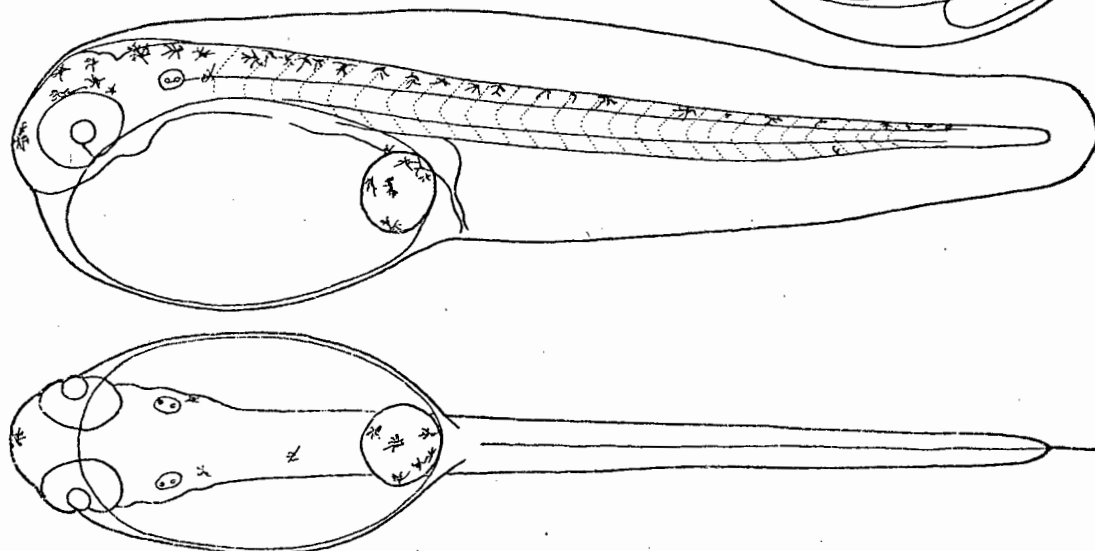


Figure 98. Diplodus sargus soon after hatching, lateral and ventral views. NL (alive) = 2,7 mm, NL (fixed) = 2,4 mm. Myomeres: 10 + 18 = 28.

ranges makes identification difficult, if not impossible. Both black and yellow pigmentation in the late embryo is very similar to that of D. sargus (see below).

Larva.

Newly-hatched larvae of D. cervinus bear xanthophores in the following places: 1) immediately anterior and posterior to each eye, 2) two (bilateral) over the middle of the yolk on the body above the level of the notochord, 3) two (bilateral) over the posterior third of the yolk on the body below the level of the notochord, 4) on the oil globule (several), 5) two (bilateral) over the oil globule on the body above the level of the notochord, 6) one (median) on the underside of the tail, about a fourth of the distance from the oil globule to the posterior tip of the notochord, 7) one (median) on the dorsal surface of the tail, slightly posterior to the level of the last-mentioned xanthophore, and 8) two on the tail, about half-way between the oil globule and the posterior tip of the notochord. Minor variations in this xanthophore distribution were noticed. Melanophore patterns at this stage are useless in separating D. cervinus from other sparids. At about 4 days, post-hatch, the black pigment along the dorsal surface of the gut begins to intensify. By first-feeding (optimally at 6-8 days post-hatch), the two Diplodus species are distinguishable on the basis of the intensity of this pigment. D. cervinus at this stage is more robust and has a more blunted snout than D. sargus. D. cervinus lacks the nuchal flare of yellow pigment that characterizes first-feeding larvae of Pterosmaris axillaris, Pachymetopon blochi, and some Lithognathus mormyrus. All xanthophores disappear in some individuals prior to first-feeding; they are normally lost in all cases by about the 10th day post-hatch (15°C). The 32-day specimen figured (fig. 96) happened to lack black pigment on the caudal portion of the vertebral column. Such pigment is often present. The ventral fins are invariably black. The vertical black bands of the adult only begin to take shape at about 2 cm (SL).

Meristics.

D XI + 12-13, A III + 11 (Smith, 1965). One specimen was reared with 10 anal soft rays. P 14-16, Vertebrae: 10 + 14 = 24 (this study).

Geographic and seasonal distribution.

Extends all round Africa (Smith, 1965). No larvae of this species hatched from eggs collected on the Atlantic side of the Cape Peninsula. The eggs were taken in False Bay from October to January, inclusive (table 1). Christensen (1976) captured three juveniles of 1-2 cm SL in tide pools near Port Alfred in November. These are likely to have been spawned about 3 months earlier, which suggests an earlier or more extended, spawning period for this species in the eastern Cape Province.

Rearing notes.

First-feeding was consistently successful on Brachionus. At 15°C, larvae developed a definitive fin-ray count at about 5 weeks, post-hatch. In all the batches of D. cervinus reared, there was a high incidence of abnormal swimming behavior. Many larvae swam at the top of the water column, inclined at a 45° angle to the surface. Juveniles behaved normally, attaining standard lengths of about 2 cm after 3 months, 3-3.5 cm after 6 months (15°C).

4.16.3 Diplodus sargus (blacktail) Figs. 97-104.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1916 (as Sargus capensis): egg, p. 5.

Ranzi, 1933 (as Sargus sargus): egg, p. 351, fig. 257; larva, p. p, 351, fig. 258, pl. 26.

(Additional references are cited by Ranzi (1933).)

Egg.

Fig. 97, table 3. The author cannot suggest any features that uniquely characterize the egg of this species.

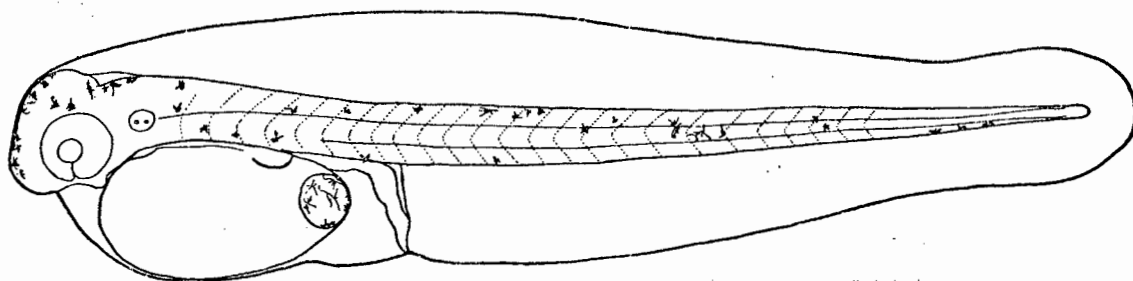


Figure 99. Diplodus sargus at 2 days (15°C). NL (alive) = 3,4 mm, NL (fixed) = 2,9 mm. Myomeres: $9 + 17 = 26$.

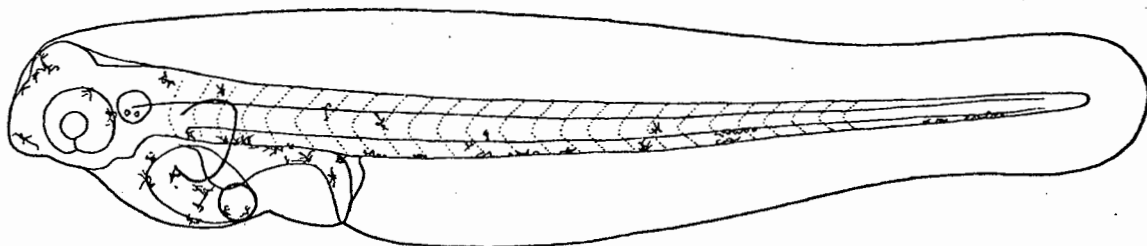


Figure 100. Diplodus sargus at 4 days (15°C). NL (alive) = 3,4 mm, NL (fixed) = 3,1 mm. Myomeres: $8 + 18 = 26$.

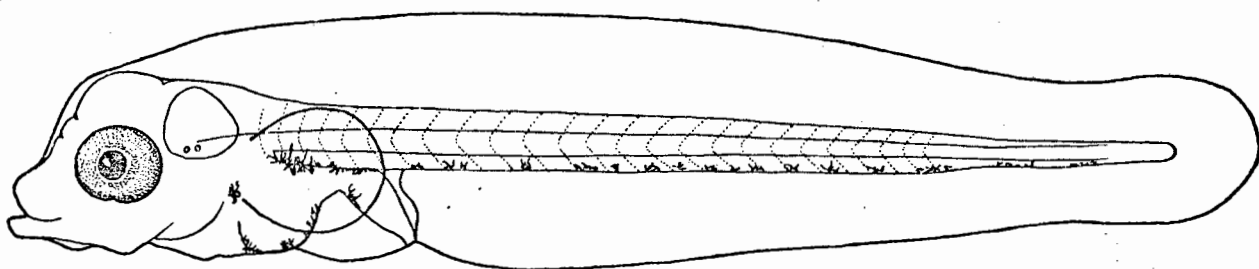


Figure 101. Diplodus sargus at 8 days (15°C). NL (alive) = 3,3 mm, NL (fixed) = 2,9 mm. Myomeres: $8 + 18 = 26$.

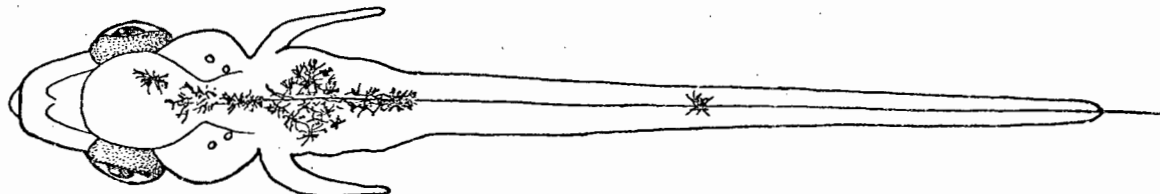
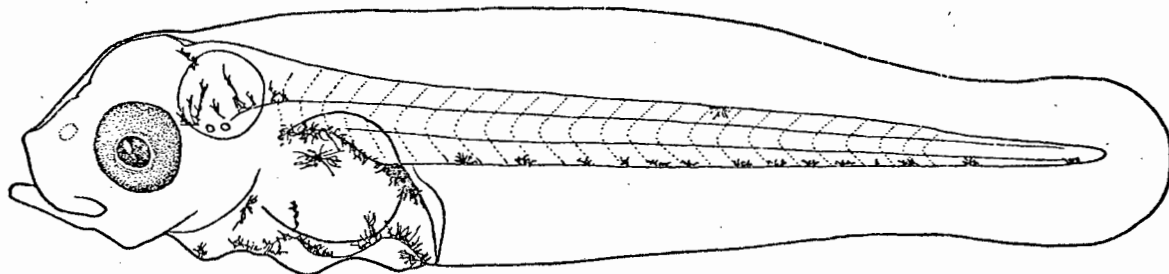


Figure 102. Diplodus sargus at 16 days (15°C), lateral and dorsal views. NL (alive) = 4,5 mm, NL (fixed) = 4,1 mm. Myomeres: $8 + 17 = 25$.

Larva.

Figs. 98-103, table 3. The distribution of xanthophores in early larvae is somewhat variable, and at present, it would be unwise to attempt generalization. The specimens figured (figs. 98-101) were not atypical. Melanophore distribution in pre-feeding larvae is not useful in separating them from other sparid species. After some practice, the author could confidently recognize living larvae of this species at first-feeding—as much by the general aspect (including facial expression!) as by pigmentation or size. Among flexion and early post-flexion larvae, the presence of melanophores along the anal fin base (fig. 103), and absence of such pigment along the soft-dorsal fin base is characteristic. The black spot on the caudal peduncle from which the species takes its South African English common name only appears at a standard length of 9-10 mm (alive).

Meristics.

D XII + 14-15, A III + 13-14 (Smith, 1965). P 16-17, Vertebrae: 10 + 14 = 24 (this study).

Geographic and seasonal distribution.

D. sargus occurs all round Africa (Smith, 1965) and as far as the Bay of Biscay in the NE Atlantic (Tortonese, 1973). The South African form has been given subspecific status (Paz, 1975) as D. sargus capensis. From egg collection data presented here (table 1), there appears to be a spawning peak in November-December, with reduced spawning the rest of the year. Spawning in the Mediterranean takes place April-June (Ranzi, 1933).

Bearing notes.

Incubation time (15°C): 74 ± 10 h (fig. 185.17). An experiment was conducted in which a group of 45 previously unfed D. sargus at age-of-optimal-first-feeding (ca. 173 h) were split into two 350-ml containers (described in Part 1 of this thesis, fig. 4), one containing Brachionus, the other

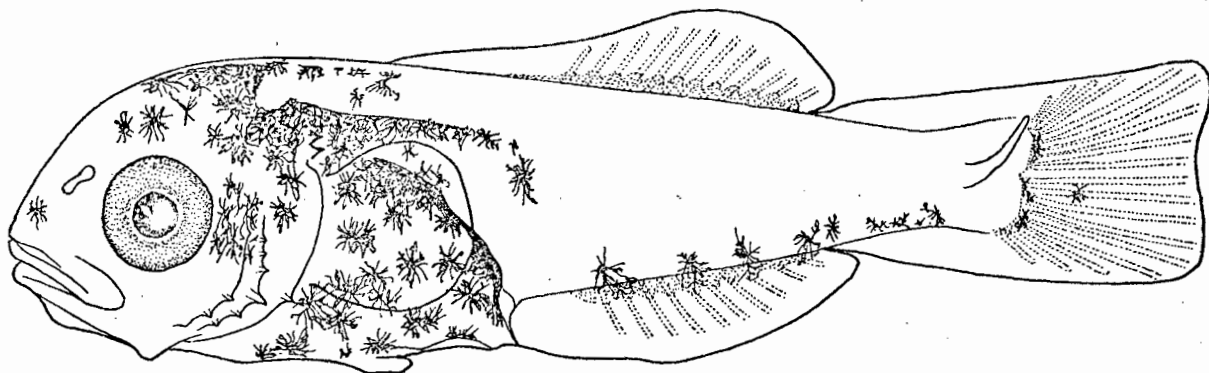


Figure 103. Diplodus sargus at 32 days (15°C). SL (alive) = 8,3 mm, SL (fixed) = 8,0 mm. Fin elements have not yet reached definitive counts.

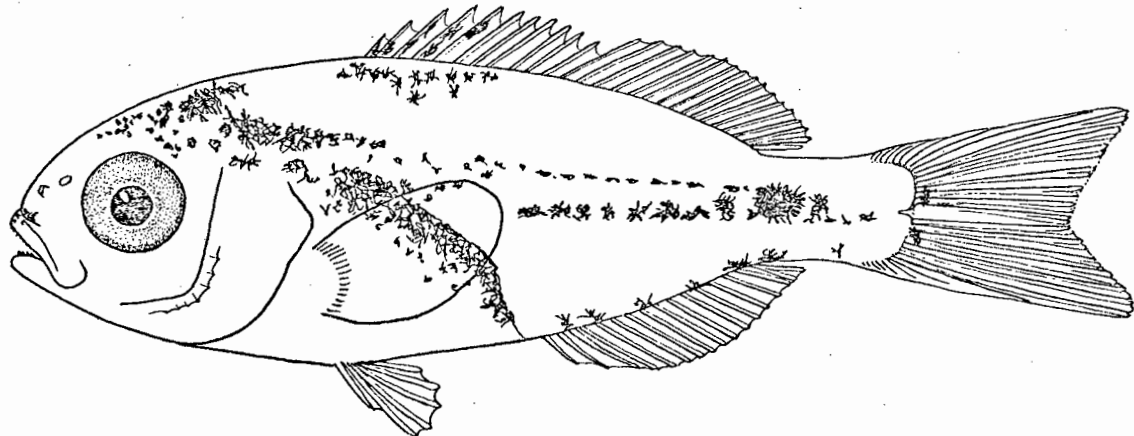


Figure 104. Diplodus sargus at 50 days (15°C). SL (alive) = 14,4 mm, SL (fixed) = 13,3 mm. D XI + 15, A III + 13, P 16.

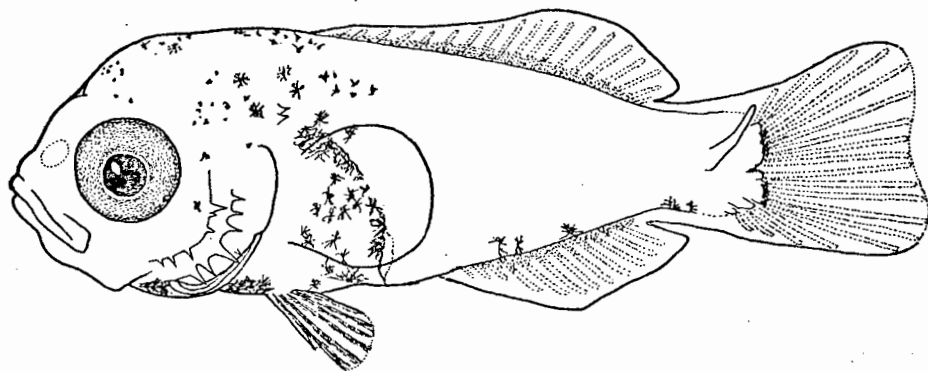


Figure 105. Gymnocrotaphus curvidens at 43 days (15°C). This specimen died in the rearing tank and was illustrated after preservation. SL (fixed) = 5,4 mm. Fin elements have not yet reached definitive counts.

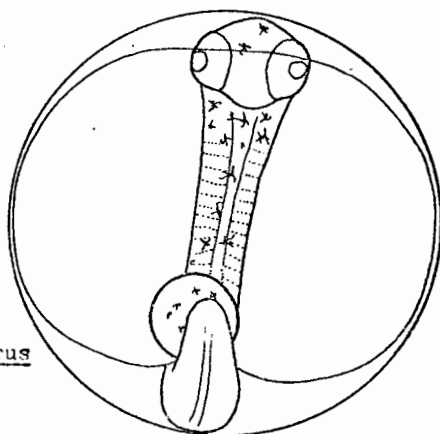


Figure 106. Lithognathus mormyrus egg. 0,85 mm in diameter, oil globule 0,18 mm.

Proales. After a 4-h exposure to food, 12 of 21 (57%) of the larvae offered Brachionus had fed and 19 of 24 (79%) of the larvae offered Proales had fed. The difference is not significant at the 5% level (Chi-square test). At least ten batches of D. sargus were reared through metamorphosis, and some were maintained for several months thereafter. Standard lengths of 6-month-old juveniles ranged from 3,5 to 5 cm (15°C).

4.16.4 Gymnocrotaphus curvidens (Janbruin) Fig. 105.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1916: egg, p. 6.

Egg.

Ripe ovarian eggs measured 0,9 mm in diameter, with a single oil globule 0,21 mm in diameter (Gilchrist, 1916). They were not recognized in this study.

Larva.

Fig. 105. On three occasions, a few larvae of this species appeared in rearing tanks stocked with assorted eggs and larvae from False Bay. They were recognized as unique about a month after hatching, but were not sacrificed for illustration in the hope that some would reach an identifiable stage. The individual figured here (fig. 105) died prior to metamorphosis and was preserved. The coloured pigmentation in the drawing was taken from a live-sketch of another specimen.

Meristics.

D X 11-12, A III 9-10 (Smith, 1965).

Geographic and seasonal distribution.

The Janbruin is endemic to South Africa: False Bay to Durban (Day et al., 1970). The above-mentioned specimens were reared from eggs collected in False Bay in October, November, and December.

Bearing notes.

One larva survived to metamorphosis. Growth was slow: a SL of 2,8 cm was reached at an age of 5 months when it died during treatment for the protozoan parasite, Cryptocaryon irritans.

4.16.5 Lithognathus mormyrus (sandsteenbras) Figs. 106-114.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Pagellus mormyrus): egg, p. 188; larva, p. 188.

Gilchrist, 1916 (as Pagellus mormyrus): egg, p. 6; larva, p. 6.

Varagnolo, 1964 (as Pagellus mormyrus): egg, p. 259, figs. 23-24; larva, p. 259, figs. 25-27.

Egg.

Fig. 106, table 3. Gilchrist (1903) gave the mean diameter of ten eggs as 0,88 mm, with an oil globule of 0,16 mm. Varagnolo's (1964) eggs, collected from the plankton of the upper Adriatic, were of the same diameter (mean 0,87, range 0,83-0,90), but the oil globule was considerably larger (ca. 0,24 mm). Even if one were to go by Varagnolo's drawings of L. mormyrus eggs, the globule would still be 0,20-0,22 mm (assuming the eggs drawn had diameters between 0,83 and 0,90 mm). Globule diameters of eggs collected during the present study ranged from 0,17 to 0,19 mm, making them somewhat larger than Gilchrist's and smaller than Varagnolo's.

Larva.

Figs. 107-113, table 3. The arrangement of xanthophores in the newly-hatched larvae was very consistent. The specimen drawn may be considered typical. Although Gilchrist's (1903: 188) description of an egg approaching hatching conforms to this xanthophore distribution, his notes on the newly-hatched larva are contradictory: "There is no aggregation of pigment at any particular points, but is scattered

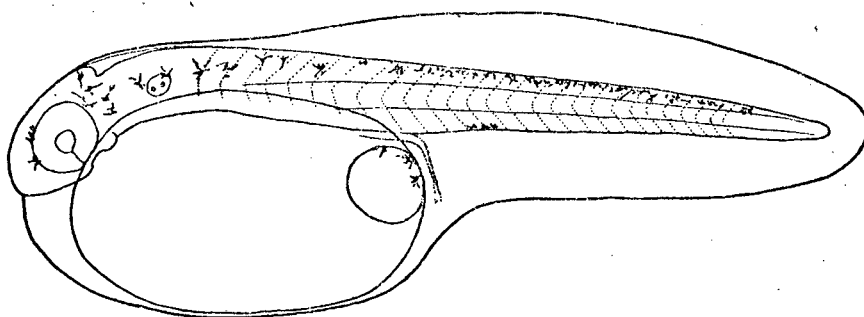


Figure 107. *Lithognathus mormyrus* soon after hatching, lateral and ventral views. NL (alive) = 2,1 mm, NL (fixed) = 2,0 mm. Myomeres: 11 + 17 = 28.

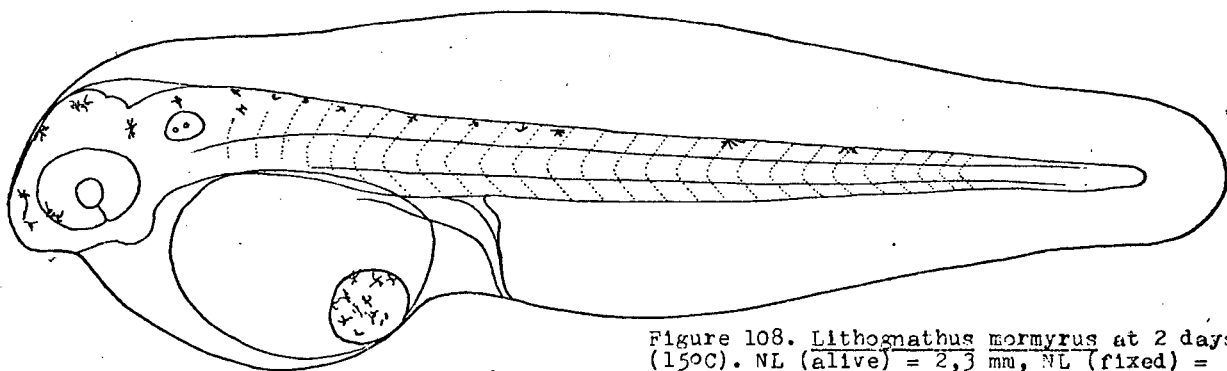
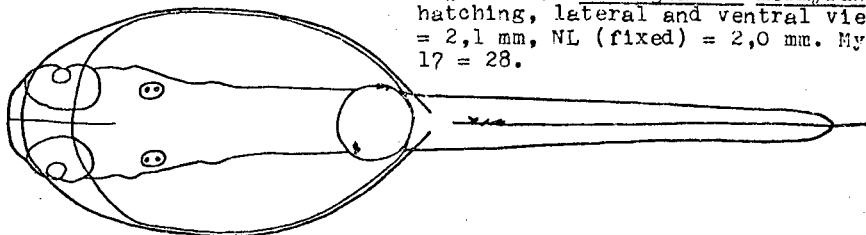


Figure 108. *Lithognathus mormyrus* at 2 days (15°C). NL (alive) = 2,3 mm, NL (fixed) = 2,0 mm. Myomeres: 11 + 17 = 28.

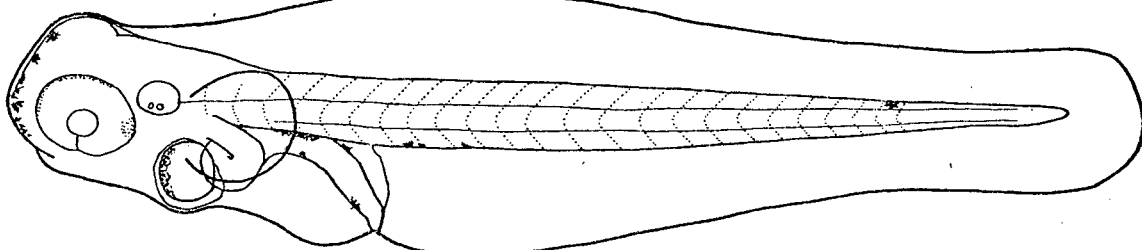


Figure 109. *Lithognathus mormyrus* at 4 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,5 mm. Myomeres: 7 + 18 = 25.

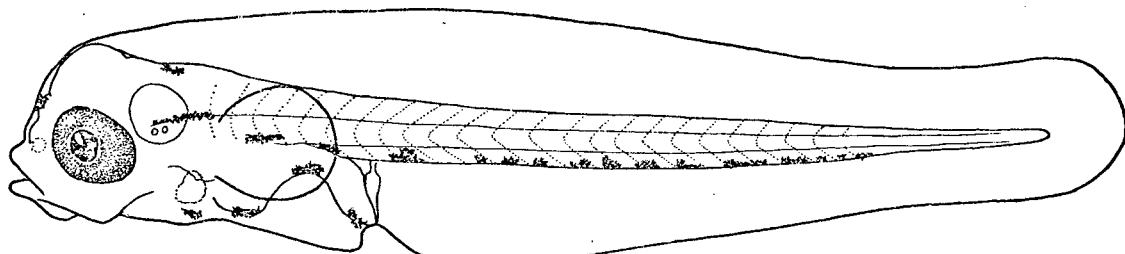


Figure 110. *Lithognathus mormyrus* at 8 days (15°C). Specimen with poorly developed yellow pigmentation. NL (alive) = 2,9 mm, NL (fixed) = 2,9 mm. Myomeres: 8 + 17 = 25.

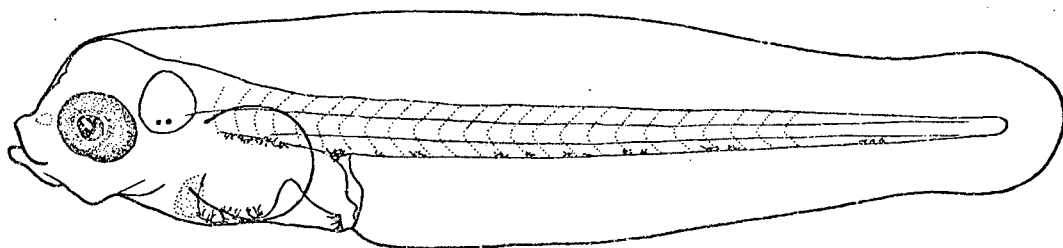


Figure 111. *Lithognathus mormyrus* at 8 days (15°C). Specimen with well-developed yellow pigmentation. NL (alive) = 3,0 mm, NL (fixed) = 2,8 mm. Myomeres: 8 + 17 = 25.

sparsely over the whole larva in dots and stellate pigment cells, sometimes extending on to dorsal and anal fin."

Varagnolo's (1964) figures of pre-feeding larvae depart in several respects from those described here. He showed yellow pigment at three places (rather than one, rarely two) on the tail, including the extreme posterior of the notochord. Also, the cephalic and thoracic xanthophores of his newly-hatched larva are scattered, rather than consolidated into well-defined areas. There are, however, enough similarities between Varagnolo's larvae and those described here to admit the possibility that both concern the same species, but that noteworthy geographic differences occur in the early stages.

Although xanthophore placement at hatching is rather constant, the same cannot be said for subsequent stages. Some larvae lose all (or almost all: fig. 110) yellow pigment prior to first-feeding, some exhibit a proliferation of yellow pigment (fig. 111). Older larvae and early juveniles bear very modest preopercular armature (unlike that shown in one of Banzi's (1933, pl. 25, fig. 14) illustrations).

Meristics.

D XI + 12, A III 10 (Smith, 1965). Specimens reared during this study: D XI + 12-13, A III + 10-11, P 16-17, Vertebrae: 10 + 14 = 24.

Geographic and seasonal distribution.

L. mormyrus ranges around the whole of Africa and into the Bay of Biscay (Smith, 1965; Tortonesc, 1973). Eggs were taken from October to February, inclusive, in False Bay; never on the Atlantic side of the Cape Peninsula.

Hearing notes.

Incubation time (15°C): 74 ± 10 h (fig. 185.18). Age-at-optimal-first-feeding is about 172 h, at least 50% of larvae can first-feed between the ages of about 140 and 204 h post-hatch. (Part 1 of this thesis). First-feeding was generally successful on Proales, generally

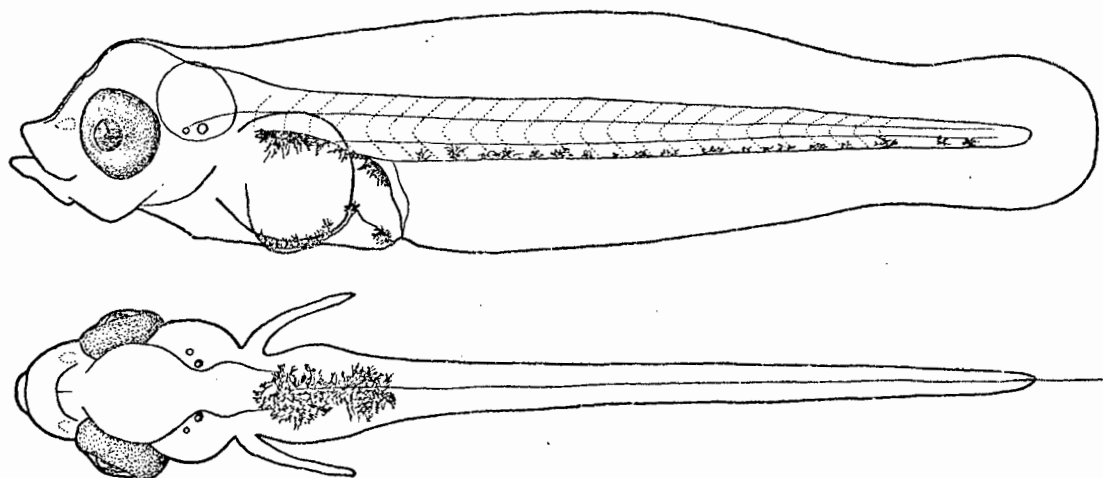


Figure 112. *Lithognathus mormyrus* at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,7 mm, NL (fixed) = 3,4 mm. Myomeres: 7 + 18 = 25.

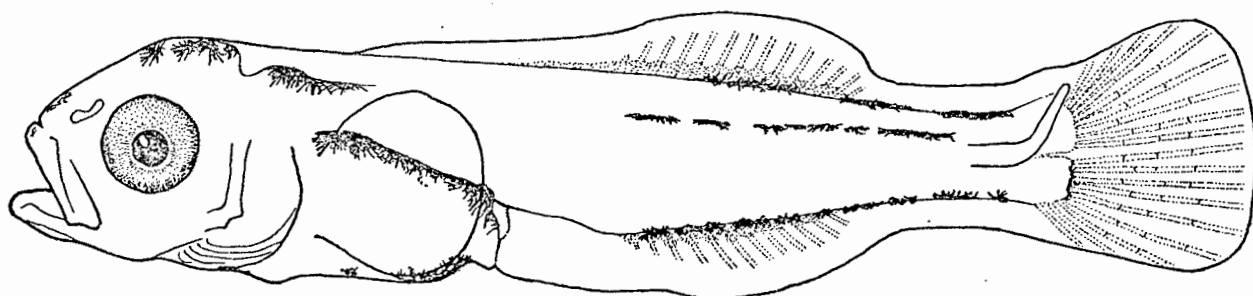


Figure 113. *Lithognathus mormyrus* at 32 days (15°C). SL (alive) = 7,5 mm, SL (fixed) = 7,0 mm. Fin elements have not yet reached definitive counts.

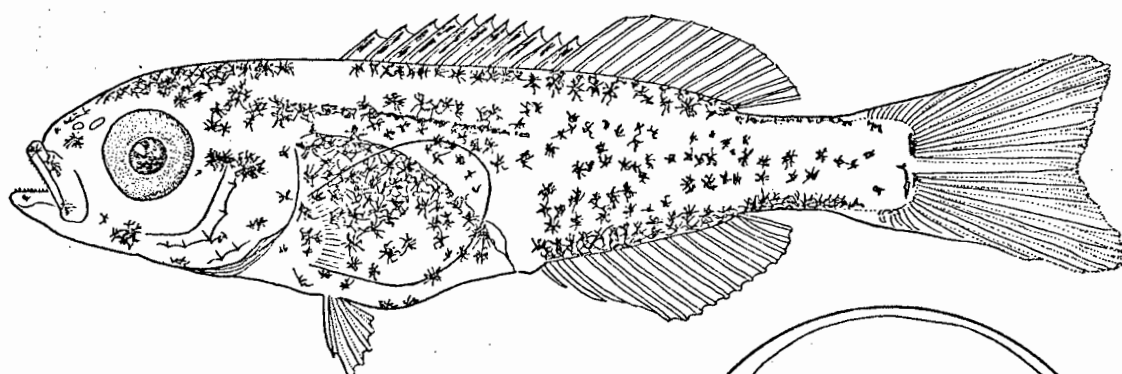


Figure 114. *Lithognathus mormyrus* at 56 days (15°C). SL (alive) = 13,1 mm, SL (fixed) = 11,7 mm. D XI + 12, A III + 11, P 16.

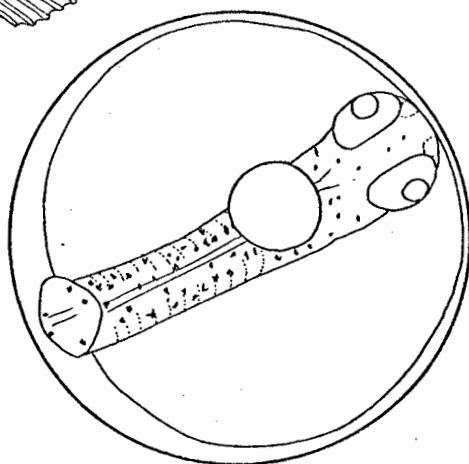


Figure 115. *Pachymetopon blochi* egg. 1,28 mm in diameter, oil globule 0,24 mm.

unsuccessful on Brachionus. The difference may be attributed to the small mouth of the larva. Juveniles averaged 3,5 cm SL at an age of 6 months.

4.16.6 Pachymetopon blochi (hottentot) Figs. 115-122.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1916 (as Cantharus blochii): egg, p. 6.

Egg.

Fig. 115, table 3. Since the meristic characters of P. blochi eggs are not unique, it is only near hatching that the egg can be identified—and even then, it is only on the basis of xanthophore arrangement in the living embryo that identification is feasible (see notes under Pterosmaris axillaris).

Larva.

Figs. 116-121, table 3. The larva at first-feeding bears a vivid flare of yellow pigment that begins between the eyes and runs postero-dorsally onto the nape (Pterosmaris axillaris has the same kind of flare at this stage). By the second or third week, the yellow pigment disappears (15°C). The early juvenile is red-orange with well-defined black areas (fig. 122).

Meristics.

D X-XI + 11-12, A III + 10 (Smith, 1965). P 16-17, Vertebrae: 10 + 14 = 24 (this study).

Geographic and seasonal distribution.

The hottentot ranges from Lüderitz to Algoa Bay (Day et al., 1970) but is rare east of Cape Agulhas (Smith, 1965). From egg collection records (table 1) there appears to be a protracted period of spawning from January to August, inclusive, with almost no activity during the rest of the year. See table 2 for additional information.

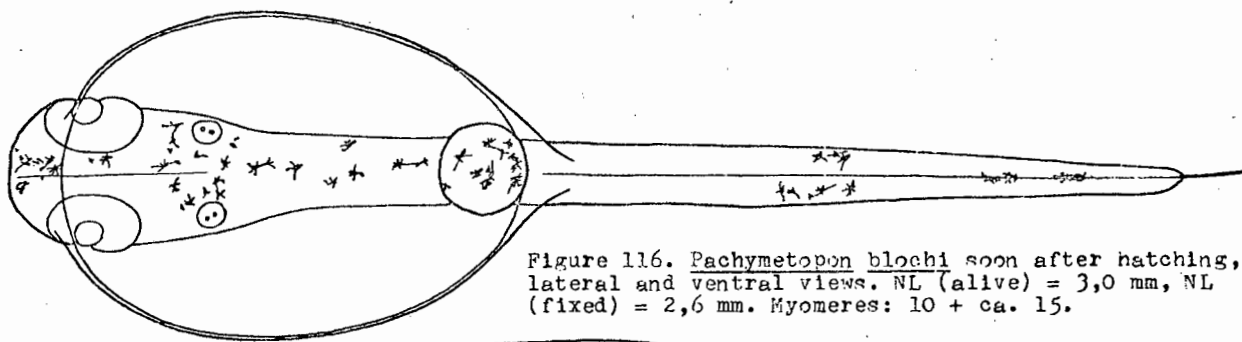


Figure 116. Pachymetopon blochi soon after hatching, lateral and ventral views. NL (alive) = 3,0 mm, NL (fixed) = 2,6 mm. Myomeres: 10 + ca. 15.

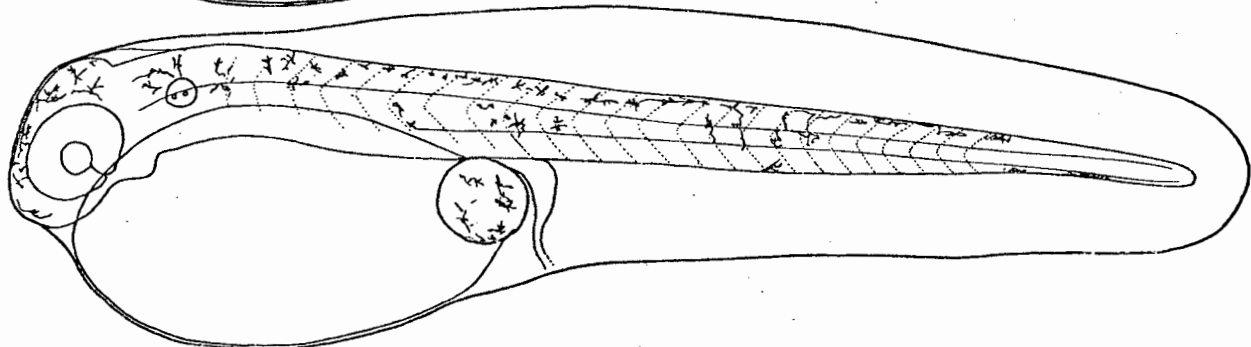


Figure 117. Pachymetopon blochi at 2 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,4 mm. Myomeres: 9 + 18 = 27.

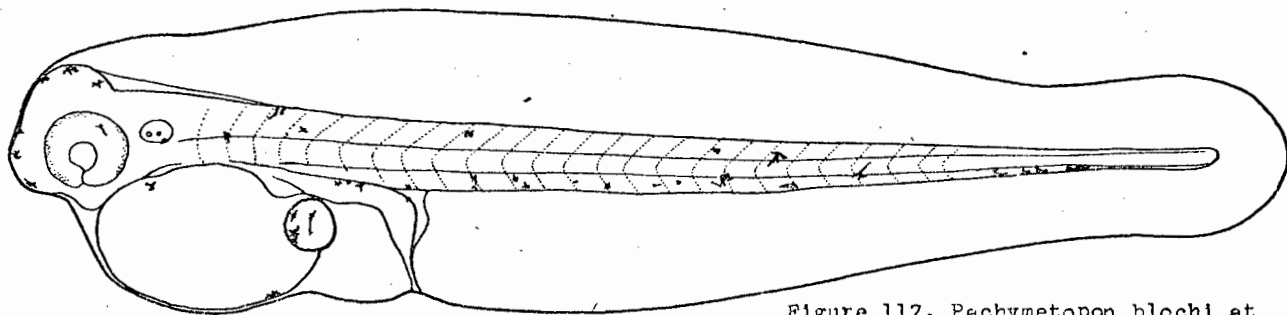


Figure 118. Pachymetopon blochi at 4 days. NL (alive) = 3,6 mm, NL (fixed) = 3,1 mm. Myomeres: 8 + 18 = 26.

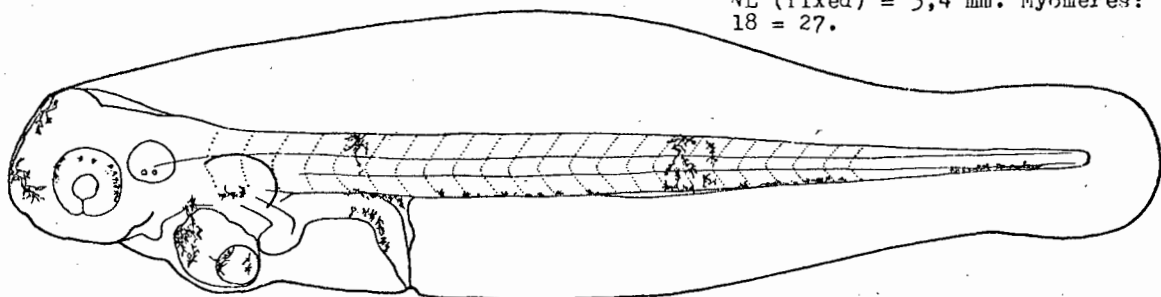


Figure 119. Pachymetopon blochi at 8 days (15°C). NL (alive) = 4,3 mm, NL (fixed) = 4,0 mm. Myomeres: 8 + 18 = 26.

Rearing notes.

Incubation period (15°C): 82 ± 10 h (fig. 185.19).

P. blochi at first-feeding is robust, active, and voracious. It feeds equally well on Proales as on Brachionus. The author reared several batches through metamorphosis and found it to be among the hardest species encountered. Two individuals were transferred to a 200-l aquarium tank and kept for 12 months. During this period they grew to a SL of 10,2 cm (average), which is roughly the expected size of a wild, one-year-old P. blochi, based on extrapolation of growth data provided by Nepgen's (1977) otolith studies.

4.16.7 Sparodon durbanensis (musselcracker) Fig. 123.Previous descriptions of eggs and/or larvae.

None.

Egg.

Not recognized.

Larva.

Not recognized. A recently metamorphosed juvenile of this species taken alive in a False Bay tide-pool has been included (fig. 123).

Meristics.

D XI + 11-12, A III + 10 (Smith, 1965).

Geographic and seasonal distribution.

Endemic to South Africa: False Bay to St. Lucia (Day et al., 1970). Judging by the size range of juveniles in False Bay tide-pools in summer (about 1,3 to at least 5 cm SL), the species must have a protracted spawning season—possibly August to January.

4.16.8 Species 5 (Sparidae) Figs. 124-128.

Previous descriptions of eggs and/or larvae.

None?

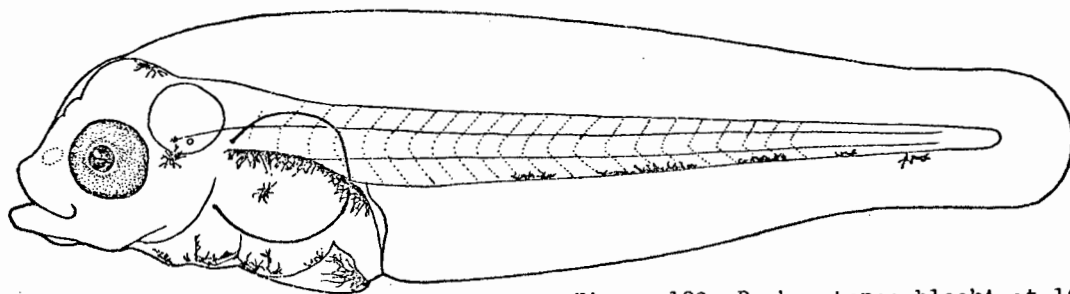


Figure 120. Pachymetopon blochi at 16 days (15°C), lateral and dorsal views. NL (alive) = 4,7 mm, NL (fixed) = 4,4 mm. Myomeres: 7 + 18 = 25.

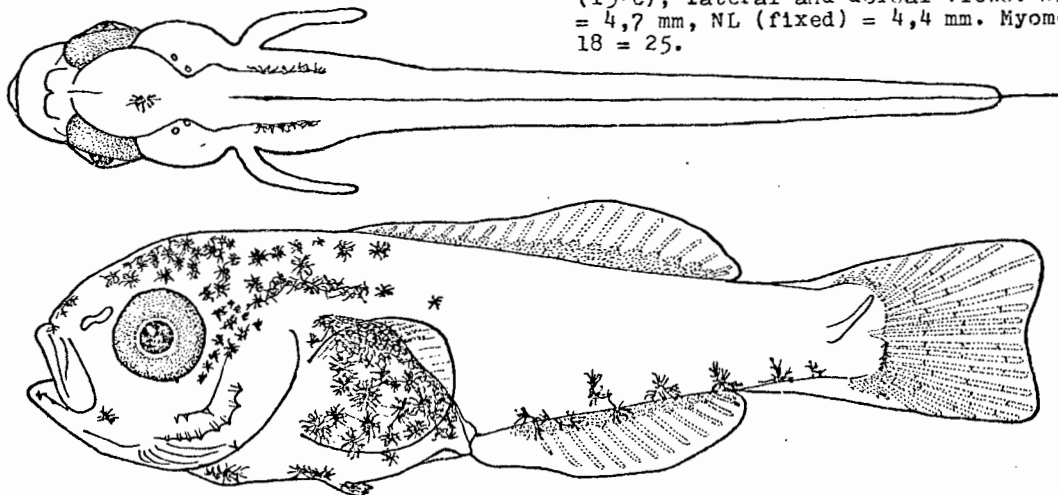


Figure 121. Pachymetopon blochi at 32 days (15°C). SL (alive) = 10,3 mm, SL (fixed) = 9,6 mm. Fin elements have not yet reached definitive counts.

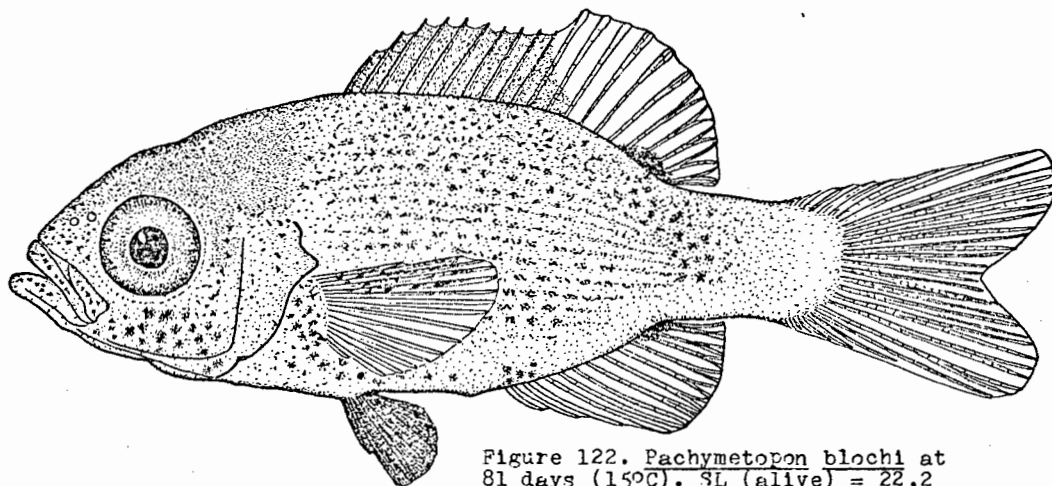


Figure 122. Pachymetopon blochi at 81 days (15°C). SL (alive) = 22,2 mm, SL (fixed) = 20,7 mm. D X + 12, A III + 10, P 16.

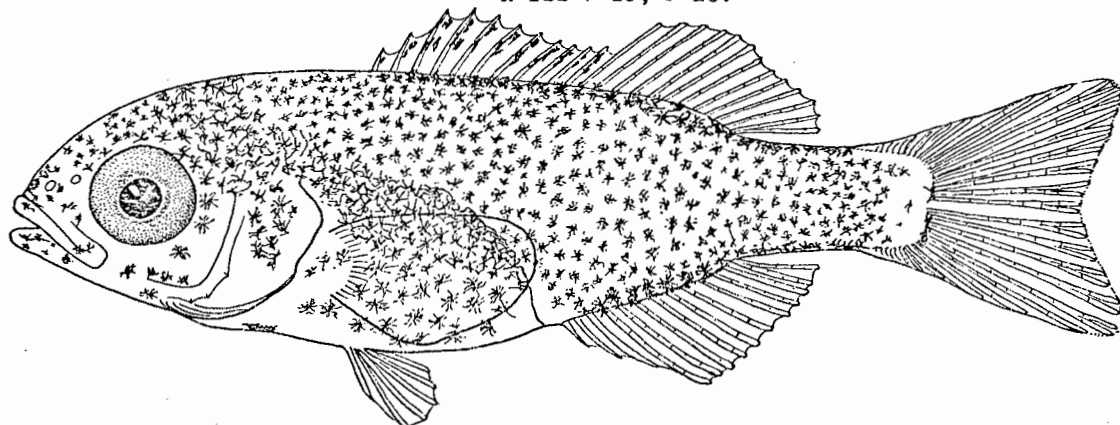


Figure 123. Sparodon durbanensis collected in a False Bay (St. James) tide pool on 6 March 1978. SL (alive) = 13,3 mm, SL (fixed) = 12,4 mm. D XI + 12, A III + 10, P 15.

Notes on identification.

The egg and pre-feeding larva is similar in many respects to those obtained by artificial fertilization of Argyrozona argyrozona (Gilchrist, 1903 (as Dentex argyrozona): egg, p. 188; larva, p. 188; and Gilchrist, 1916 (as Dentex argyrozona): egg, p. 3; larva, p. 3). Gilchrist's eggs were smaller (0,83-0,89 mm rather than 0,98-1,05 mm) and there are a few differences in xanthophore distribution. His larvae at hatching apparently lacked the caudal xanthophore of the present material. Similarities include the weak development of pigment, either yellow or black, and the absence of pre-orbital xanthophores. From examination of A. argyrozona gonads, Nepgen (1977: 19) concluded that spawning occurred "mainly" in spring and summer. This does not necessarily contradict the temporal distribution of eggs in the plankton recorded here (i.e., year-round; table 1).

Egg.

Fig. 124, table 3. The range of chorion and oil globule diameters of this egg overlaps that of several other species; prior to development of yellow pigment it is not identifiable using morphological criteria.

Larva.

Figs. 125-128, table 3. At hatching, the larva usually has five areas of yellow pigment: a spot behind each eye, a spot on the postero-dorsal surface of the oil globule, and two spots (laterally, opposite one another) on the tail. A few additional spots are sometimes present laterally on the trunk over the yolk. The distribution of the five yellow areas is similar to that in newly-hatched Pterosmaris axillaris, whose spawning period overlaps. The eggs of the two species may be separated by size alone; living yolk-sac larvae may be separated on characteristics of the xanthophores: in Species 5 the post-orbital spots are small, pale but distinct, and well-separated from one another (fig. 125); in P. axillaris they are larger and brighter

Figure 124. Species 5 (Sparidae) egg.
0,90 mm in diameter, oil globule 0,19 mm.

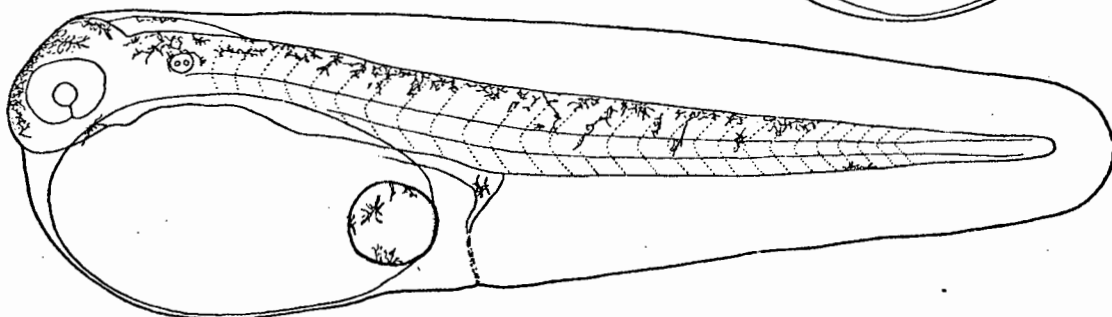
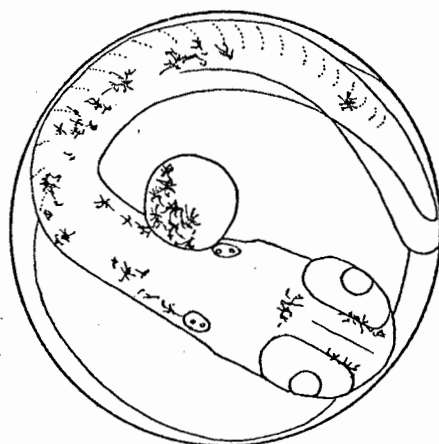


Figure 125. Species 5 (Sparidae) soon after hatching, lateral and ventral views. NL (alive) = 2,5 mm, NL (fixed) = 2,2 mm. Myomeres: 11 + 17 = 28.

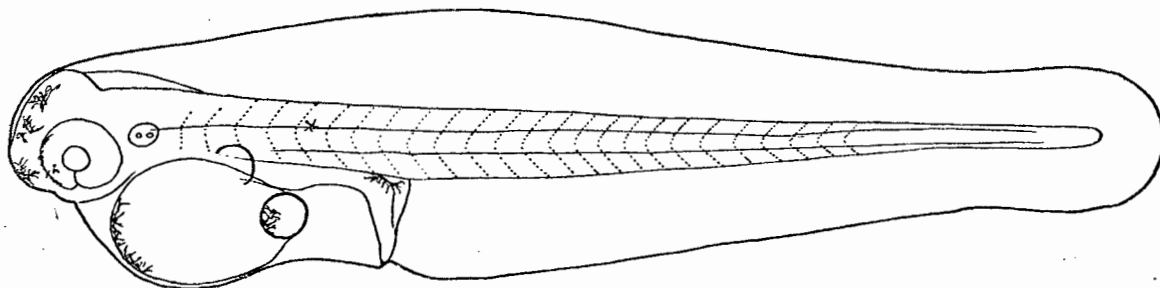
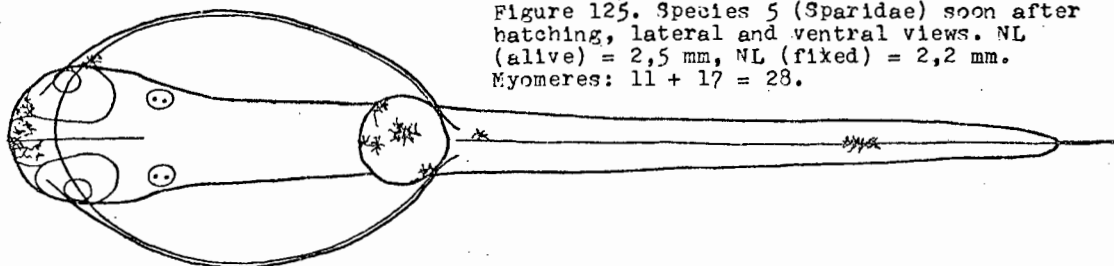


Figure 126. Species 5 (Sparidae) at 2 days (15°C). NL (alive) = 3,5 mm, NL (fixed) = 3,1 mm. Myomeres: 9 + 17 = 26.

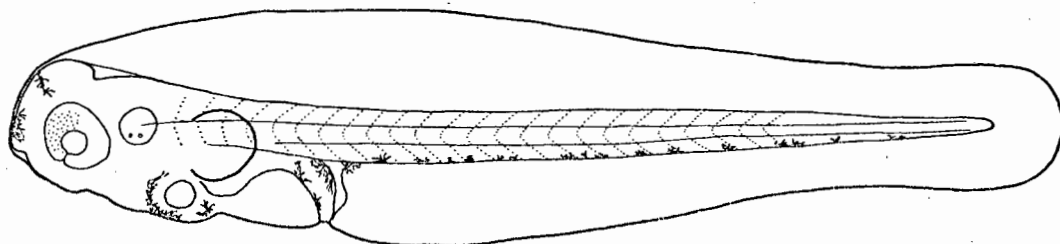


Figure 127. Species 5 (Sparidae) at 4 days (15°C). NL (alive) = 3,4 mm, NL (fixed) = 2,8 mm. Myomeres: 8 + 17 = 25.

but more diffuse, with stellate branches that may intertwine with those of the other spot, sometimes giving the impression of a single median xanthophore (fig. 86). The caudal spots behave similarly.

At first-feeding in Species 5, the only yellow pigment remaining is that of the post-orbital xanthophores, which take up a median position between the eyes; a broad yellow tail-band is normally present in P. axillaris at this stage.

Geographic and seasonal distribution.

The eggs were taken sporadically all year on both sides of the Cape Peninsula (table 1). In general, their abundance was maximal from January to March, inclusive.

Bearing notes.

Incubation time (15°C): 74 ± 10 h (fig. 185.20). First-feeding was successful on Proales but no larvae survived to a stage where fin-ray counts could be undertaken. First-feeding was optimal over the range ca. 150-200 h post-hatch (Part 1 of this thesis).

4.17 MUGILIDAE

Only two of the 15 mugilid species recognized (Smith, 1975; Elst & Wallace, 1976) from South Africa occur in Cape Peninsula waters (Smith, 1965; Day et al., 1970): Liza richardsoni and Mugil cephalus. Identification of the former was secured by rearing. Early stages of the cosmopolitan M. cephalus have been described repeatedly in the literature. The dimensions of the chorion and oil globule vary according to region and author, but most published values fall in the range 0,60-1,00 mm for the chorion diameter and 0,26-0,38 for the oil globule diameter (Yashouv & Berner-Samsonov, 1970; Robertson, 1975b). No eggs fitting the description of M. cephalus were taken during this study.

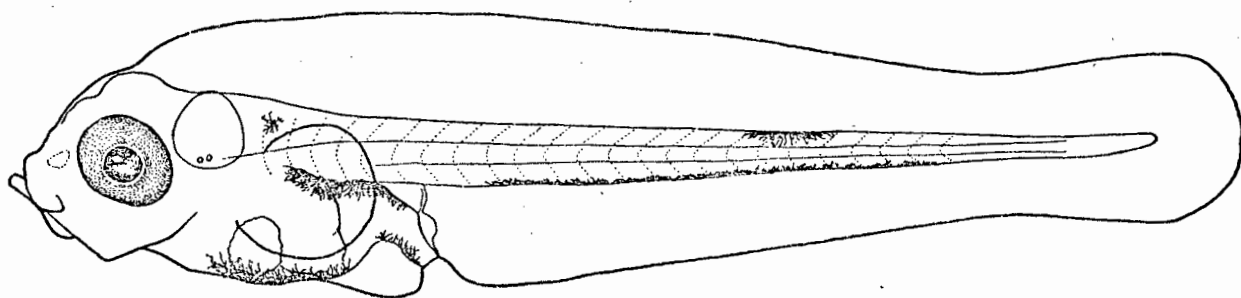


Figure 128. Species 5 (Sparidae) at 16 days (15°C), lateral and dorsal views. NL (alive) = 4,2 mm, NL (fixed) = 3,9 mm. Myomeres: 8 + 17 = 25.

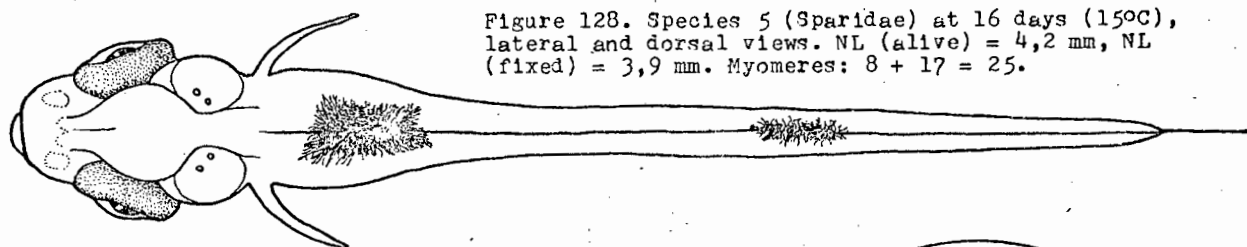


Figure 129. *Liza richardsoni* egg. 0,93 mm in diameter. The largest oil globule in this egg at time of drawing was 0,22 mm. Coalescence of all the globules would yield a globule of ca. 0,36 mm.

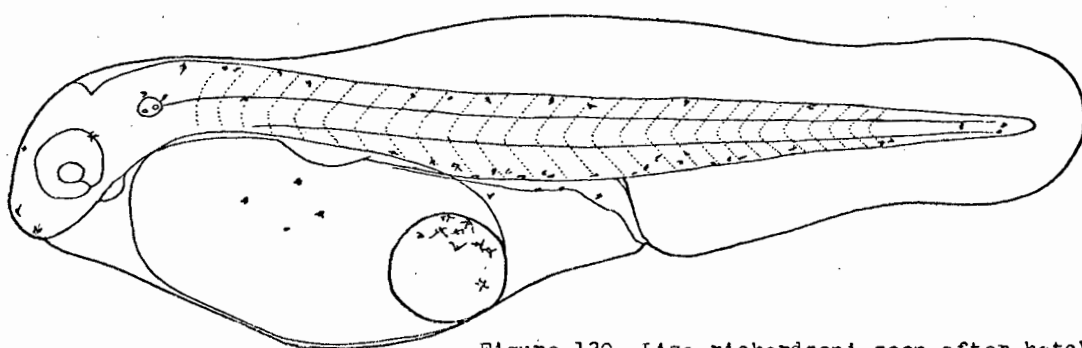
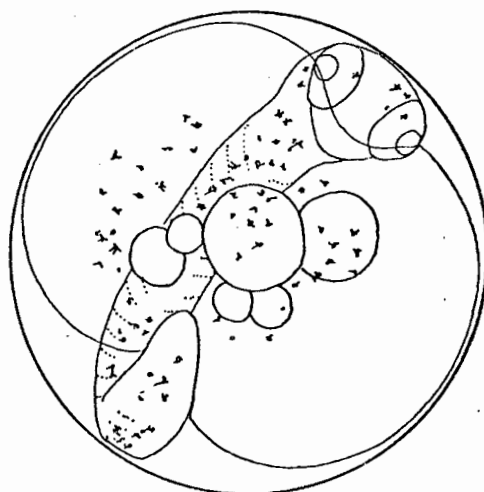
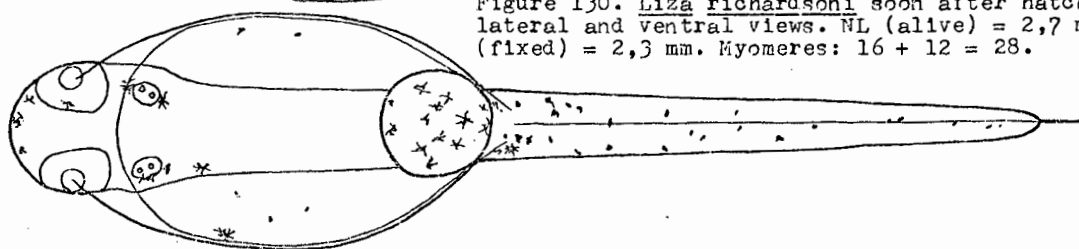


Figure 130. *Liza richardsoni* soon after hatching, lateral and ventral views. NL (alive) = 2,7 mm, NL (fixed) = 2,3 mm. Myomeres: 16 + 12 = 28.



Gilchrist (1916: as Mugil auratus) described ovarian eggs of the blue-tail mullet (ranges from Knysna eastward), Valamugil buchanani. Wallace (1975b) published information on reproduction in several other Natal mugilid species. A key to juvenile stages of South African mullets was prepared by Elst & Wallace (1976).

4.17.1 Liza richardsoni (southern mullet) Figs. 129-134.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Fig. 129, table 3. Eggs in the earliest stages usually have more than one oil globule (up to 6 were counted in eggs collected during this study), but these consolidate into a single large globule, 0,30-0,36 mm in diameter, as hatching approaches.

Larva.

Figs. 130-134, table 3. The placement of the anus in the posterior half of the body and the myomere count of $15-16 + 11-12 = 26-28$ clearly distinguishes this larva from all others described, with the exception of Species 8 (figs. 174-177). The latter is much more heavily endowed with black pigment than is L. richardsoni.

Meristics.

D IV + I + 8-9, A III 9 (Smith, 1965: as Liza ramada).

Geographic and seasonal distribution.

According to Day et al. (1970), L. richardsoni occurs along the entire southern African coast. The eggs were taken intermittently, in very small numbers, on both sides of the Cape Peninsula (table 1).

Bearing notes.

The chorion of the living egg has non-wetting properties (as does the egg of Gaidropsarus capensis). In clean, static sea water, without a surface slick, the egg almost

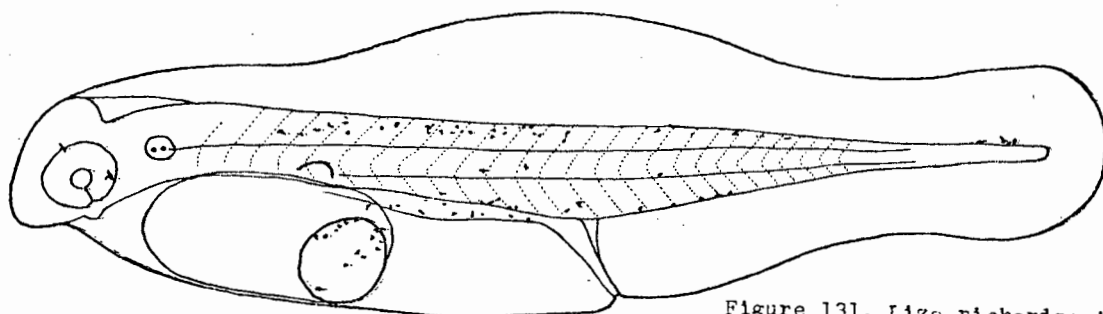


Figure 131. *Liza richardsoni* at 2 days (15°C). NL (alive) = 3,3 mm, NL (fixed) = 2,8 mm. Myomeres: 16 + 11 = 27.

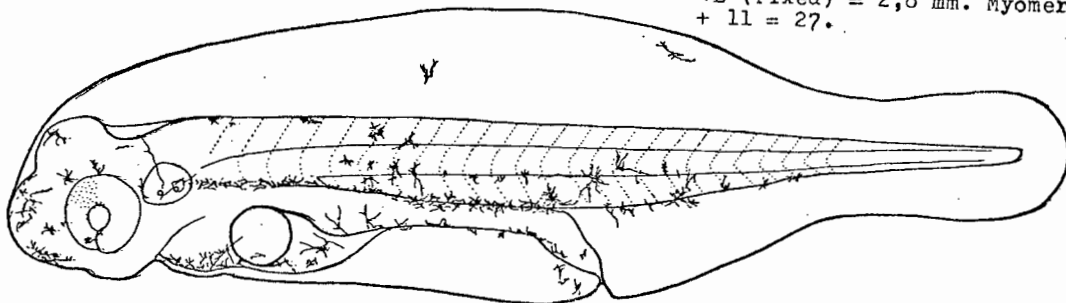


Figure 132. *Liza richardsoni* at 4 days (15°C). NL (alive) = 3,5 mm, NL (fixed) = 3,2 mm. Myomeres: 15 + 11 = 26.

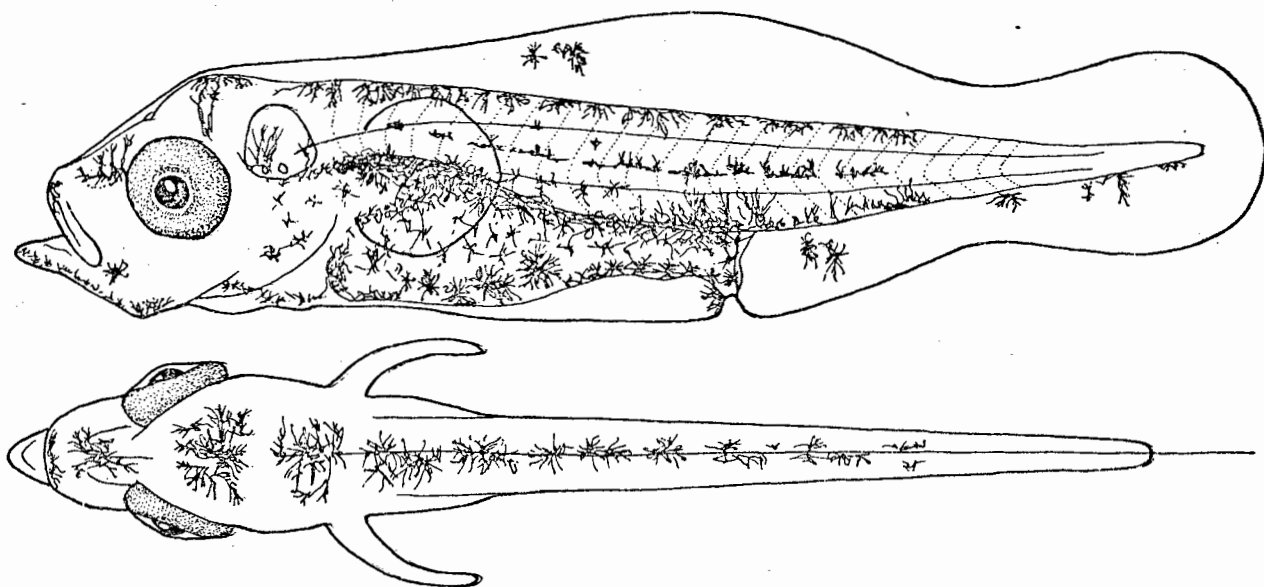


Figure 133. *Liza richardsoni* at 16 days (15°C), lateral and dorsal views. NL (alive) = 4,6 mm, NL (fixed) = 3,8 mm. Myomeres: 15 + 11 = 26.

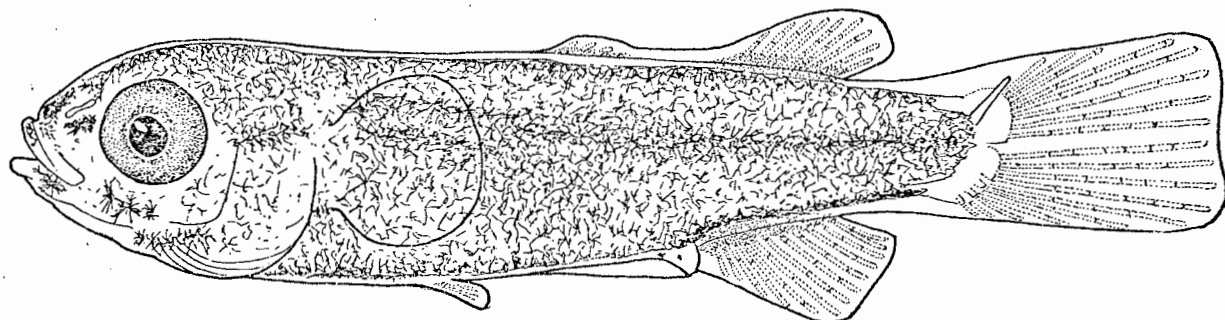


Figure 134. *Liza richardsoni* at 32 days (15°C). SL (alive) = 8,2 mm, SL (fixed) = 7,6 mm.

always breaches the surface, exposing itself to air. Mortalities through hatching were about 75% under these circumstances. Survival was considerably improved when the eggs were separated from the surface by a nylon mesh. First-feeding was successful on Brachionus. Four of about 25 larvae not sacrificed for drawings survived through metamorphosis, which occurred over the period 6-8 weeks post-hatch (15°C).

4.18 SCORPAENIDAE

This family is represented by five species in Cape of Good Hope waters. Pelagic eggs of three of these species, Helicolenus dactylopterus, Sebastichthys capensis, and Coccotropsis gymnoderma, were collected during this study. The latter two were reared through metamorphosis. Eggs of the fourth species, Scorpaena scrofa, were not encountered, but they have been described from Mediterranean material as being elliptical and lacking an oil globule (Spartà, 1956). Early stages of Trachyscorpia capensis, the fifth species in these waters, have never been described.

4.18.1 Coccotropsis gymnoderma (smoothskin scorpion fish) Figs. 135-141.

Previous descriptions of eggs and/or larvae.

none

Egg.

Fig. 135, table 3. The egg of C. gymnoderma is slightly larger, but otherwise very similar, to that of the Cape sole, Heteromycteris capensis. Both lack an oil globule, both become heavily speckled with yellow pigment as hatching approaches. Unlike some scorpaenid eggs, the eggs of this species are spherical. The egg drawn, for example, had a minor axis of 98% that of the major axis. This much non-sphericity may be produced by the embryo and is not uncommon in nominally spherical eggs.

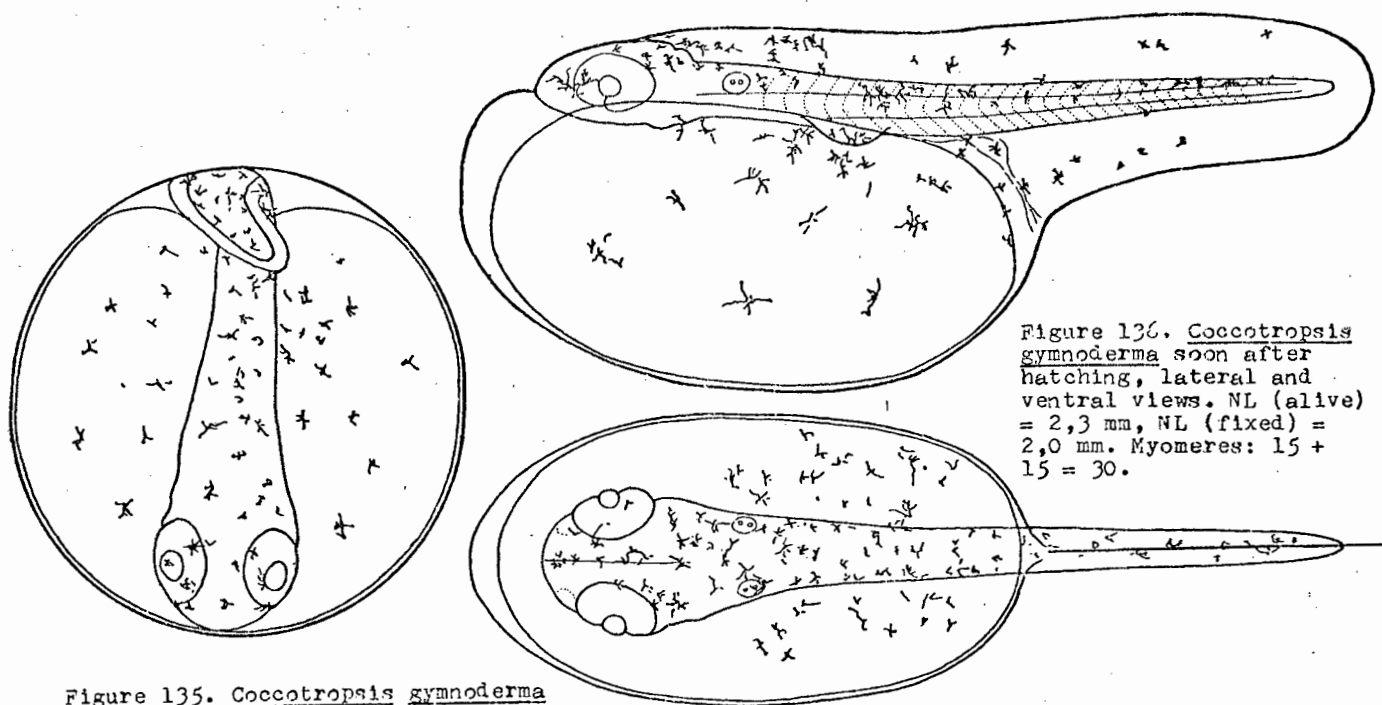


Figure 135. Coccotropsis gymnotus
egg. 1,14 mm in diameter.

Figure 136. Coccotropsis gymnotus soon after hatching, lateral and ventral views. NL (alive) = 2,3 mm, NL (fixed) = 2,0 mm. Myomeres: 15 + 15 = 30.

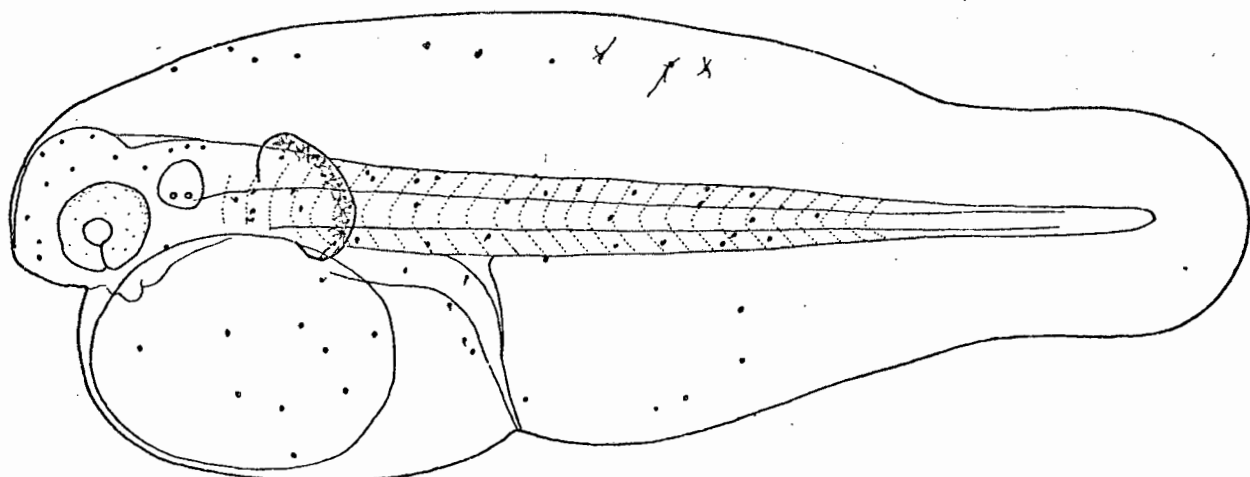


Figure 137. Coccotropsis gymnotus at 2 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,6 mm. Myomeres: 13 + 16 = 29.

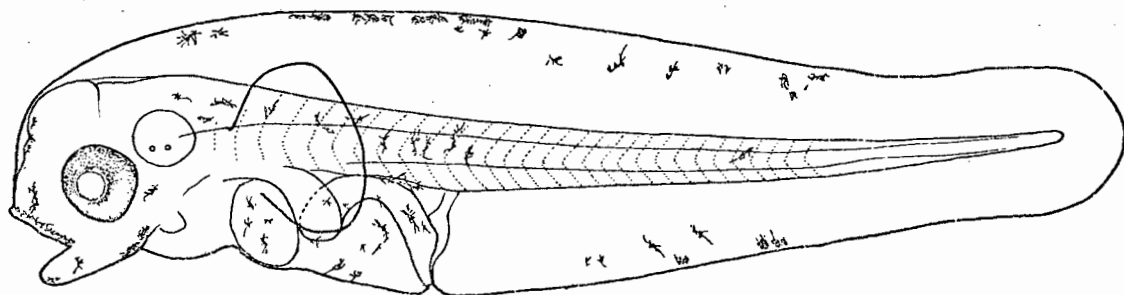


Figure 138. Coccotropsis gymnotus at 4 days (15°C). NL (alive) = 3,3 mm, NL (fixed) = 3,0 mm. Myomeres: 11 + 20 = 31.

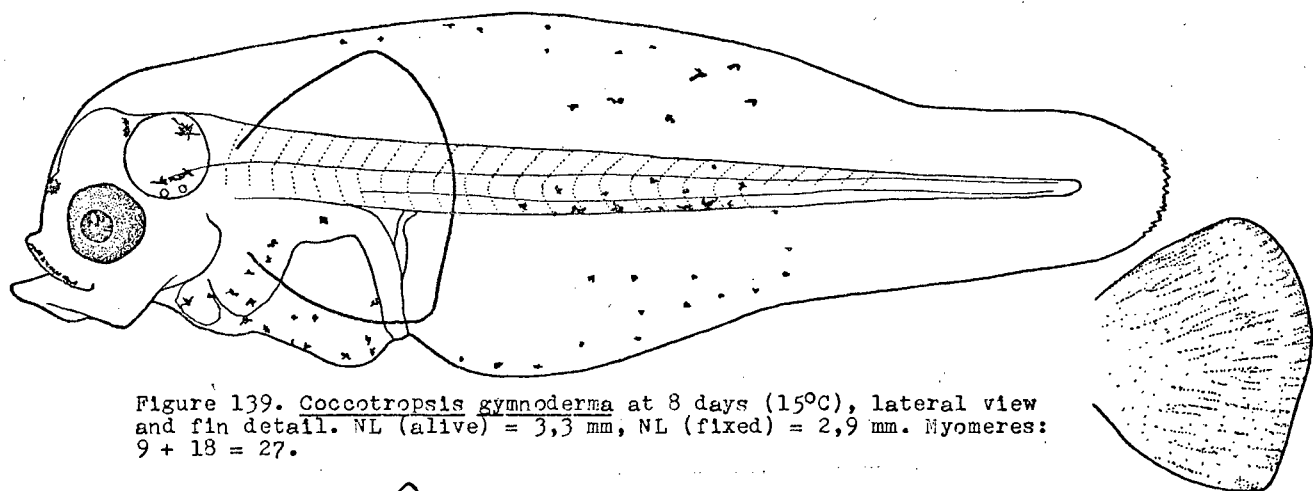


Figure 139. Coccotropsis gymnodeuma at 8 days (15°C), lateral view and fin detail. NL (alive) = 3,3 mm, NL (fixed) = 2,9 mm. Myomeres: 9 + 18 = 27.

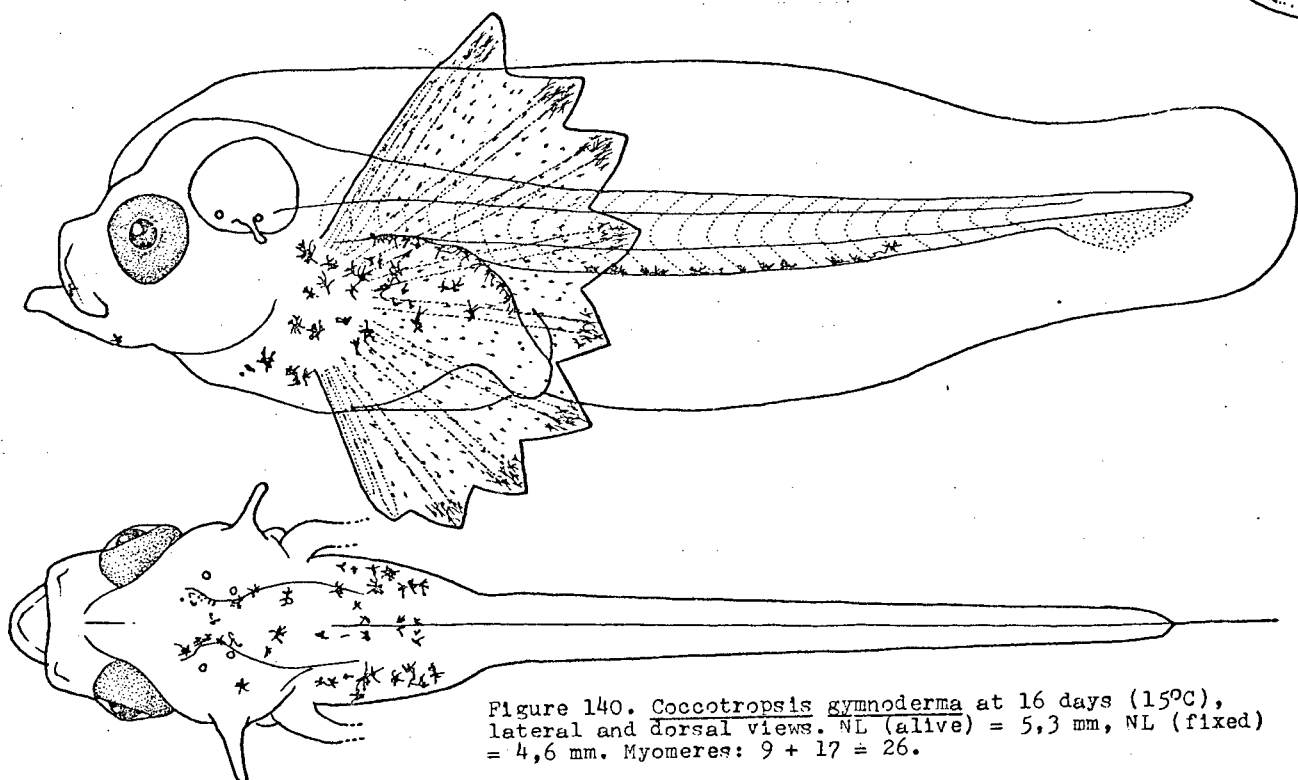


Figure 140. Coccotropsis gymnodeuma at 16 days (15°C), lateral and dorsal views. NL (alive) = 5,3 mm, NL (fixed) = 4,6 mm. Myomeres: 9 + 17 = 26.

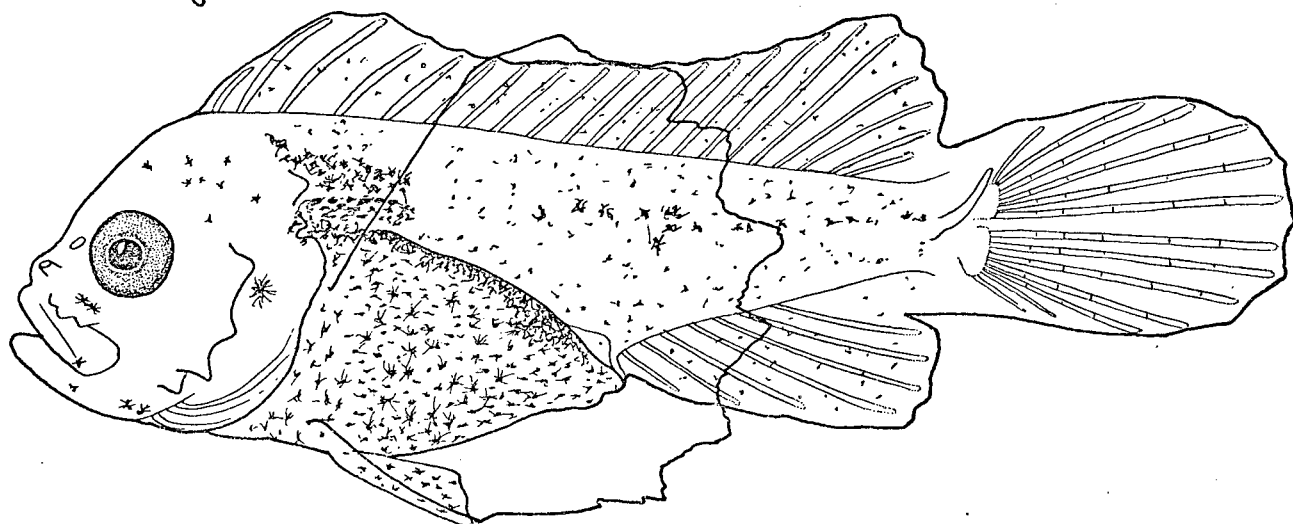


Figure 141. Coccotropsis gymnodeuma at 32 days (15°C). SL (alive) = 7,2 mm, SL (fixed) = 6,7 mm. D XV + 6, A III + 4, P 11.

Larva.

Figs. 136-140, table 3. At hatching, the larva is covered, except for the tail tip, in stellate xanthophores. There is no concentration of yellow pigment in a vertical band on the tail as is the case with newly-hatched Heteromycteris. The yolk sac is (usually) more dorso-ventrally flattened than in H. capensis, and often extends anteriorly beyond the level of the snout. The extension from each otocyst (fig. 140) develops at about 2 weeks of age (15°C) and disappears between the third and fourth week.

Meristics.

D XV + 5-6, A III + 4 (Smith, 1965). P 11.

Geographic and seasonal distribution.

Coccotropsis is a monotypic genus with distribution restricted to the south coast of South Africa, from the Cape Peninsula to Algoa Bay (Smith, 1965). Eggs were collected in False Bay during the summer (table 1).

Bearing notes.

Not enough data are available to confidently estimate incubation time for this species. The egg with the longest incubation time hatched 46 ± 6 h after it was collected (fig. 185.23). Although sea temperatures at collection varied from 18-22°C, survival of larvae at 15°C was excellent. Brachionus is readily taken at first-feeding, which may occur between the ages of 130 and 200 h post-hatch (15°C). The individual illustrated in fig. 141 is just post-metamorphic.

4.18.2 Helicolenus dactylopterus (Jacopever) Figs. 142-146.

Previous descriptions of eggs and/or larvae.

Sparta, 1956 (as Scorpaena dactyloptera): larva, p. 619, figs. 500-502, pls. 38-39.

Marinero, 1968: egg, p. 133, pl. 1; larva, p. 133, fig. B, pls. 2-3.

Haigh, 1972a: larva, p. 60, figs. 6-8.

Moser et al., 1977: larva, p. 38, fig. 23.

(Additional references are cited by Sparta (1956) and Moser et al. (1977).)

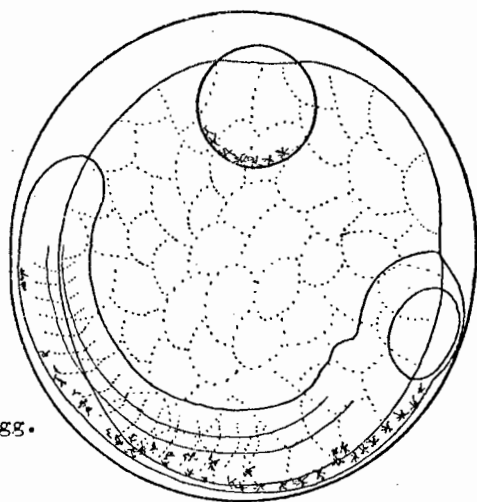


Figure 142. Helicolenus dactylopterus egg. Major axis 0,94 mm, minor axis 0,90 mm, oil globule 0,24 mm.

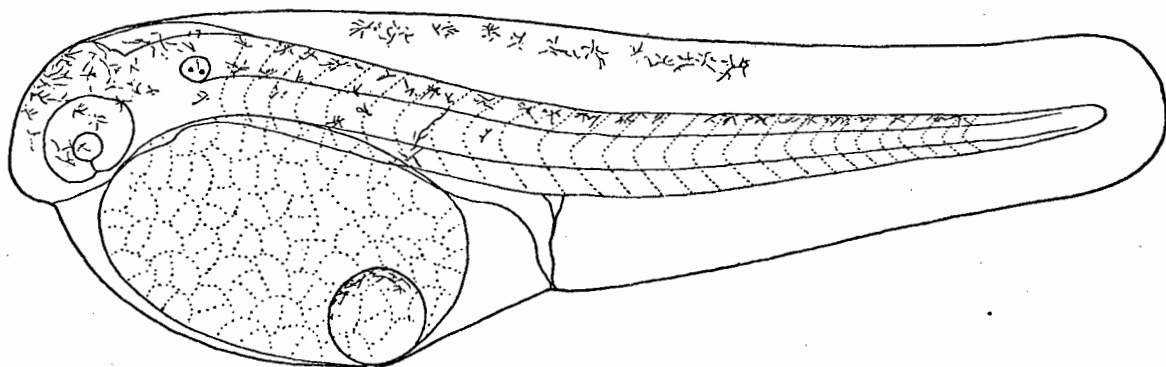


Figure 143. Helicolenus dactylopterus soon after hatching, lateral and ventral views. NL (alive) = 2,6 mm, NL (fixed) = 2,2 mm. Myomeres: 12 + 16 = 28.

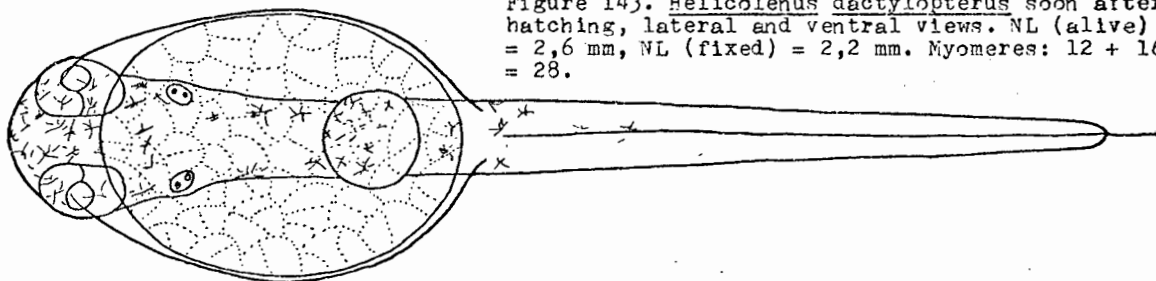


Figure 144. Helicolenus dactylopterus at 2 days (15°C). NL (alive) = 3,2 mm, NL (fixed) = 2,9 mm. Myomeres: 10 + 18 = 28.

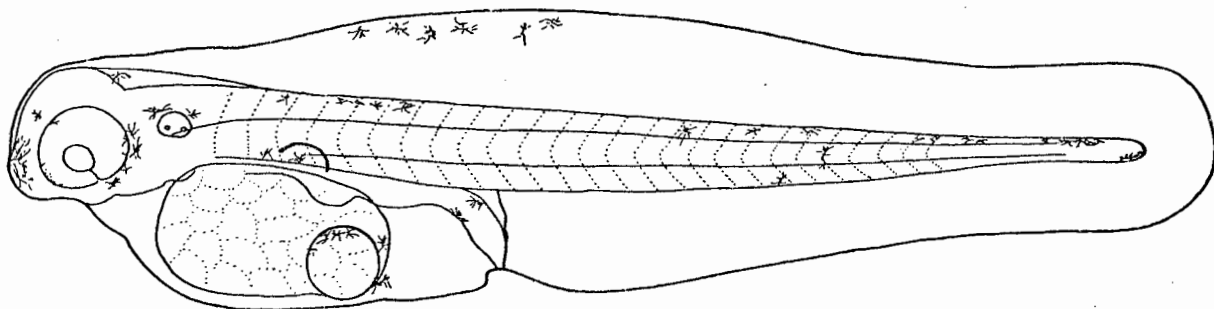


Figure 145. Helicolenus dactylopterus at 4 days (15°C). NL (alive) = 3,5 mm, NL (fixed) = 3,2 mm. Myomeres: 10 + 17 = 27.

Egg.

Fig. 142, table 3. The egg is distinguishable from all others described here by a combination of its non-sphericity, yolk vesiculation, and presence of an oil globule. The oil globule of False Bay eggs was larger (0,23-0,25 mm) than that of the Mediterranean eggs described by Marinaro (0,19-0,20 mm).

Larva.

Figs. 143-146, table 3. The refringent granules illustrated by Marinaro (1968) in the integument of the newly-hatched larva are also apparent in the present material. The peculiar profile of the snout seen in the 8-day specimen (fig. 146) was a feature common to all the individuals examined and is apparently not a deformity.

Meristics.

D XII + 13, A III 5 (Smith, 1965). Eschmeyer (1969) reported a wider range of fin elements, but his material was drawn from a much wider area. He reported: P 19 (16-21), Vertebrae: 25 (usually).

Geographic and seasonal distribution.

The range of the subspecies H. d. dactylopterus includes the western Atlantic from Nova Scotia to Venezuela, and the eastern Atlantic from Norway to South Africa (Eschmeyer, 1969). Day et al. (1970) report it as far east as Durban. The eggs were taken in False Bay in January and February, never on the Atlantic side of the Cape Peninsula (table 1).

Bearing notes.

There is evidence of internal fertilization in this species (Kreff, 1961). It would appear that extrusion of eggs may occur at various times thereafter. No record was made of the stage of development of the embryos at the time of collection. Out of the 100 eggs identified, 97 hatched during the first 57 h following collection, 3 hatched during the subsequent 12 h (fig. 185.25). Judging from the immature appearance of the larvae on hatching (not so apparent in the individual illustrated here (fig. 143)), which may

be up to 6 h old, but very apparent in the individual photographed by Marinaro (1968, pl. 2)), these eggs could not have been extruded in an advanced state of development.

The interval between hatching and completion of eye pigmentation is unusually long in this species: ca. 140 h at 15°C. First-feeding (Brachionus or Proales) incidence was generally poor (<50%). No larvae survived to an age of 16 days.

4.18.3 Sebastichthys capensis (false jacoever) Figs. 147-153.

Previous descriptions of eggs and/or larvae.

None (The 7,2 mm SL larva from the SE Pacific illustrated by Moser et al. (1977, fig. 21E) as "Sebastes capensis (?)" differs in several notable respects from the similarly sized larva illustrated here (fig. 152). It is highly unlikely that they are conspecific.)

Egg.

Fig. 147, table 3. For all practical purposes, the egg is spherical: the length of the minor axis was never found to be less than 98% (and was usually between 99 and 100%) that of the major axis.

Larva.

Figs. 148-152, table 3. The vesiculation of the yolk and the ventro-posterior (rather than dorso-posterior) position of the oil globule at hatching is probably the most noticeable difference between this species and the several sparids with similarly-sized eggs. The arrangement of melanophores like small lumps on the dorsal surface of the oil globule (fig. 149) was a general feature in 2-day-old larvae. Most specimens lost all yellow pigment by the age of 16 days. It is not known whether the absence of nuchal and parietal spines in the 32-day larva figured (fig. 152) is typical for S. capensis at this stage. This was the only larva over 16 days that was preserved, and it bore no trace of such spines.

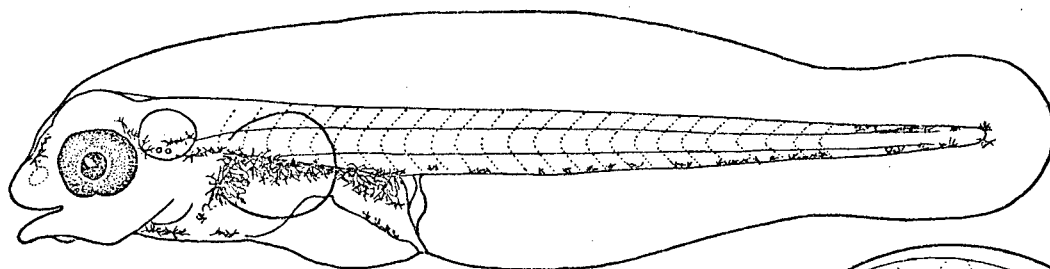


Figure 146. Helicolenus dactylopterus at 8 days (15°C). NL (alive) = 3,8 mm, NL (fixed) = 3,3 mm. Myomeres: 9 + 17 = 26.

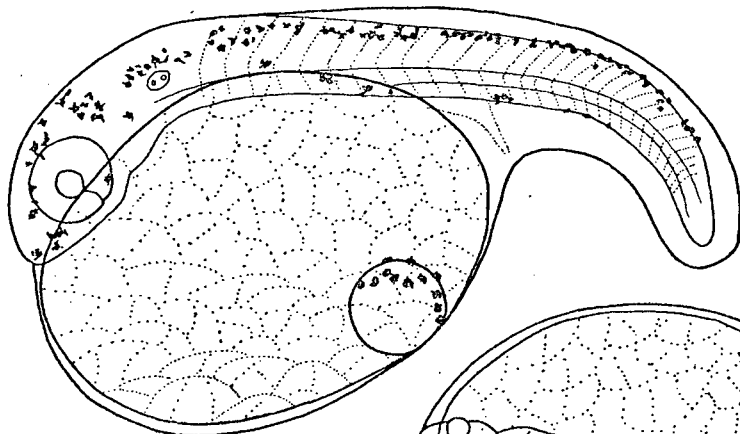


Figure 148. Sebastichthys capensis soon after hatching, lateral and ventral views. NL (alive) = 1,4 mm, NL (fixed) = 1,3 mm. Myomeres: 14 + 17 = 31.

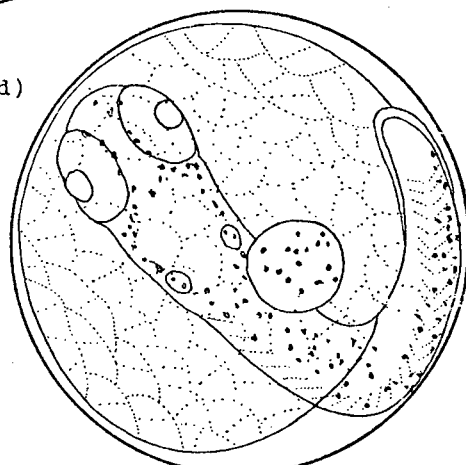


Figure 147. Sebastichthys capensis egg. Major axis 0,91 mm, minor axis 0,90 mm, oil globule 0,20 mm.

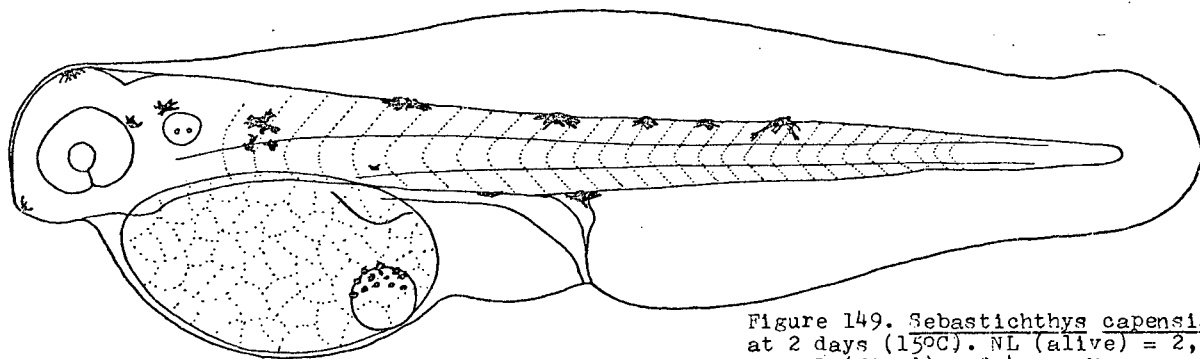
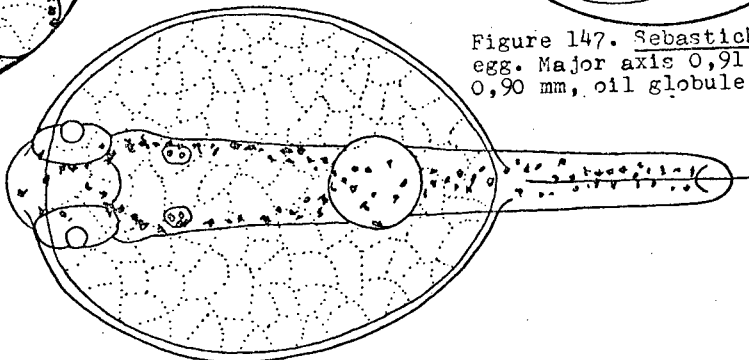


Figure 149. Sebastichthys capensis at 2 days (15°C). NL (alive) = 2,8 mm, NL (fixed) = 2,4 mm. Myomeres: 13 + 16 = 29.

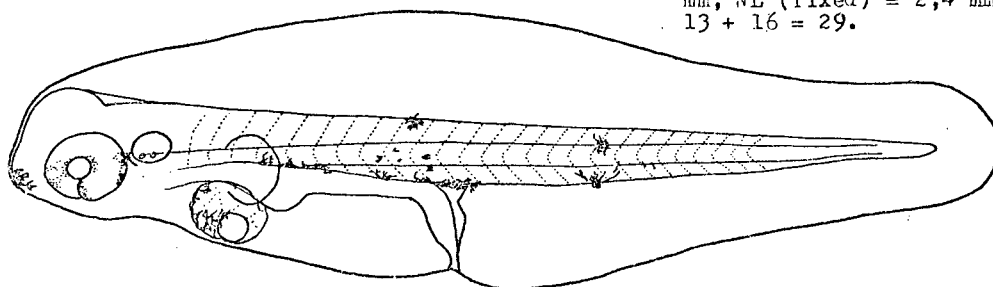


Figure 150. Sebastichthys capensis at 4 days (15°C). NL (alive) = 3,1 mm, NL (fixed) = 2,7 mm. Myomeres: 12 + 15 = 27.

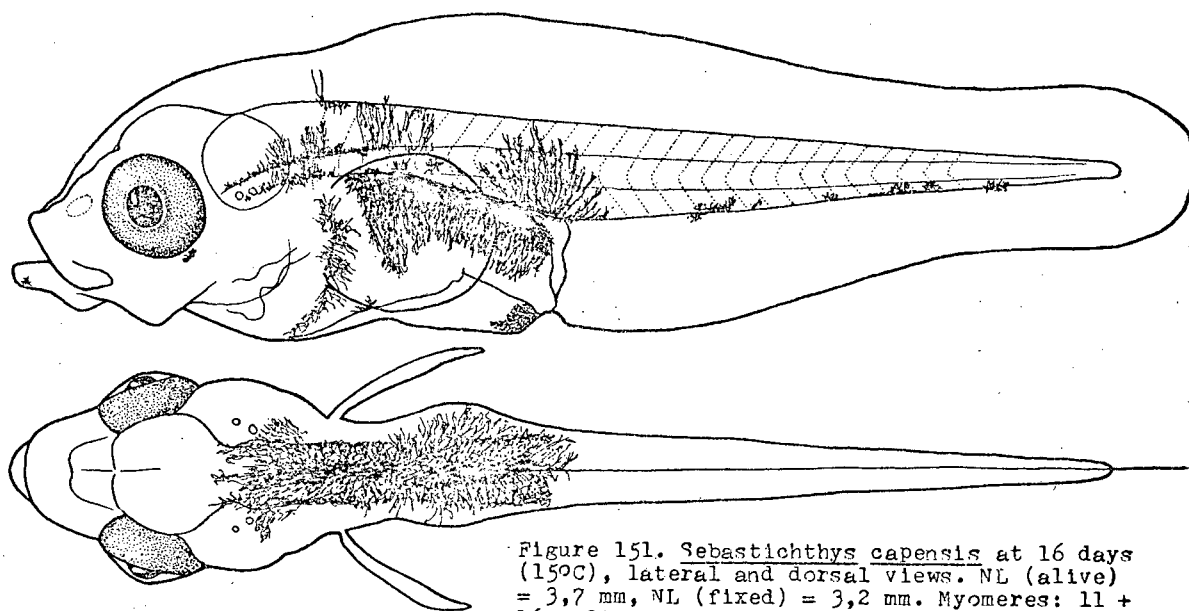


Figure 151. Sebastichthys capensis at 16 days (15°C), lateral and dorsal views. NL (alive) = 3,7 mm, NL (fixed) = 3,2 mm. Myomeres: 11 + 16 = 27.

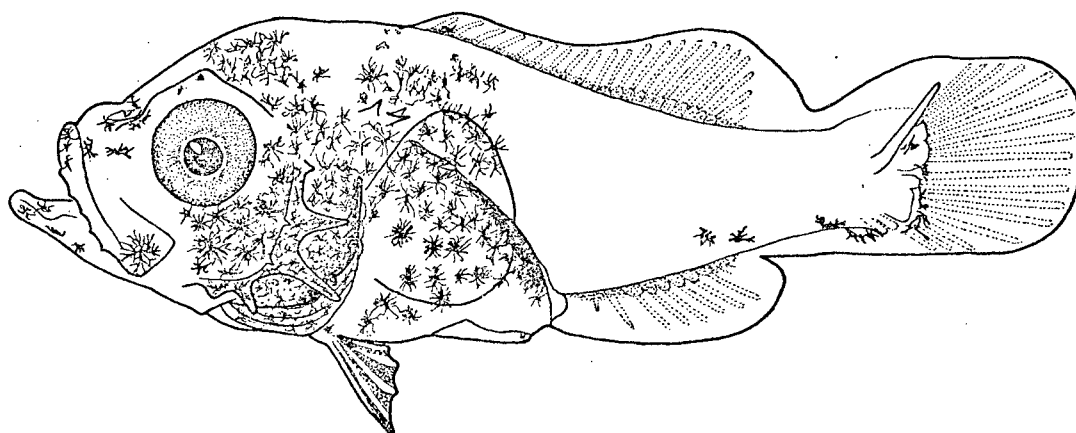


Figure 152. Sebastichthys capensis at 32 days (15°C). SL (alive) = 6,9 mm, SL (fixed) = 6,4 mm.

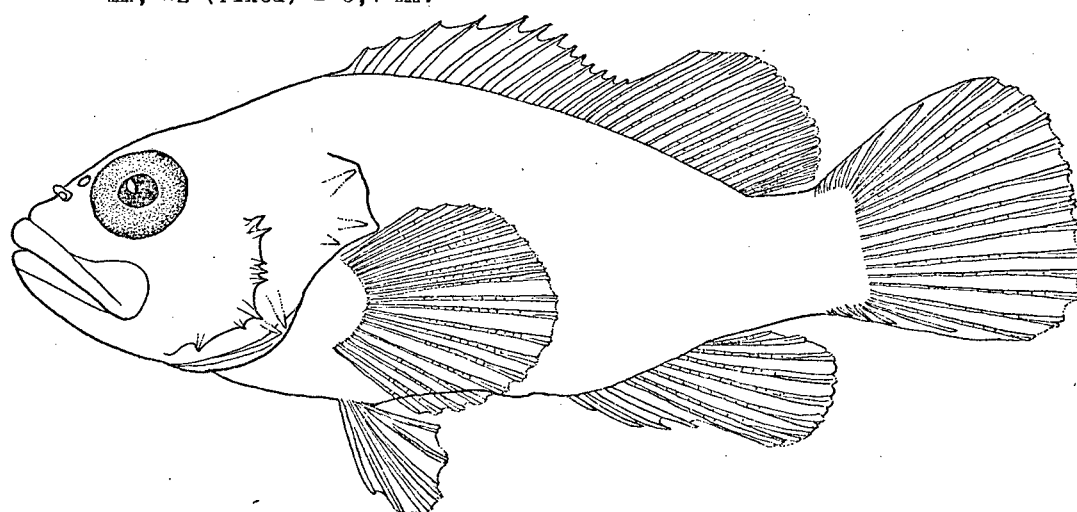


Figure 153. Sebastichthys capensis at 93 days (15°C). SL (alive) = 25,1 mm, SL (fixed) = 24,5 mm. D XIII + 15, A IV + 7, P 20.

Meristics.

D XIII-XIV + 13-14, A III + 6, P 18 (Smith, 1965). The single specimen reared through metamorphosis (fig. 153) yielded a slightly different ray-count: D XIII + 15, A IV + 7, P 20. Eschmeyer (1969) reported 26 vertebrae.

Rearing notes.

Barnard (1925-1927) regarded this species as viviparous and in his generic diagnosis of Sebastichthys, he noted the presence of a genital papilla in the male. Internal fertilization is definitely a possibility. Most of the eggs hatched between 48 and 60 h after collection (15°C) (fig. 185.21), in a relatively immature state (fig. 148). First-feeding incidence varied widely from batch to batch. The highest recorded was 76% (16 out of 21 larvae offered Proales for 4 h). Only one individual survived through metamorphosis. At a SL of 9 mm, it took up a benthic life-style and gradually acquired a variegated orange colouration.

4.19 CONGIOPODIDAE

This family consists of a total of eight southern hemisphere species (Hureau, 1970), of which two (Congio-
podus torvus, C. spinifer) are known from southern Africa. Both occur at the Cape of Good Hope. The identification of the eggs and larvae described below as C. spinifer was made on the basis of successful rearing through metamorphosis. One cannot exclude the possibility, however, that eggs of both species were taken, but that only C. spinifer happened to survive to an identifiable stage.

Gilchrist (1903) described ovarian eggs of a horsefish he identified as Agriopus verrucosus (synonymized by Barnard (1925-1927) with C. torvus). His 1904 publication described artificially fertilized eggs and a late embryo of Agriopus spinifer (synonymized by Barnard with C. spinifer). Although the C. spinifer eggs (1,74-1,83 mm) were slightly larger than the C. torvus eggs (1,53-1,7 mm), there was some doubt as to the maturity of the latter, as

Figure 154. Congiopodus spinifer egg.
1,82 mm in diameter.

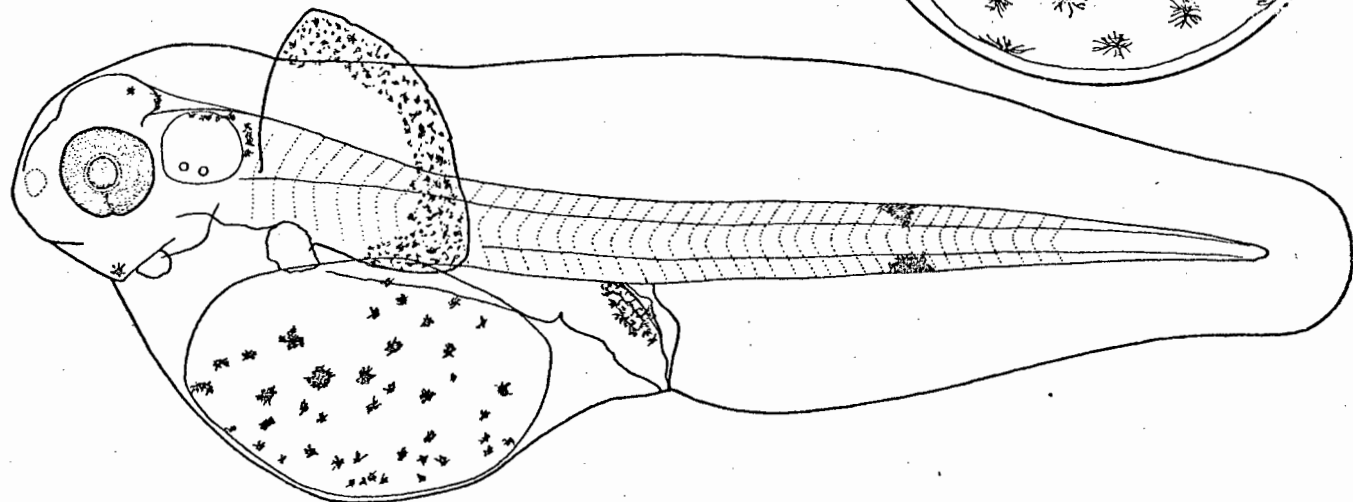
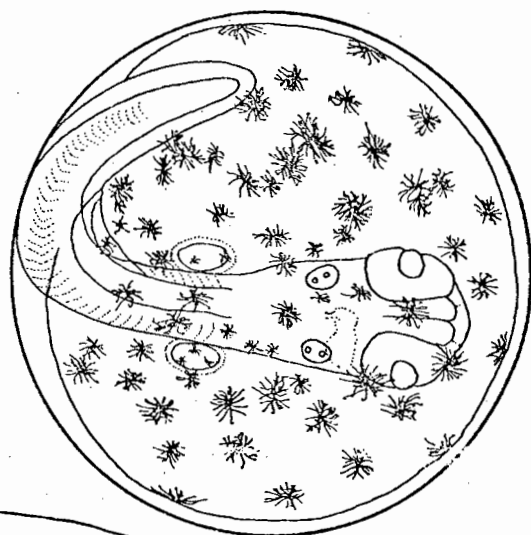


Figure 155. Congiopodus spinifer soon after hatching,
lateral and ventral views. NL (alive) = 5,3 mm, NL
(fixed) = 5,0 mm. Myomeres: 22 + 22 = 44.

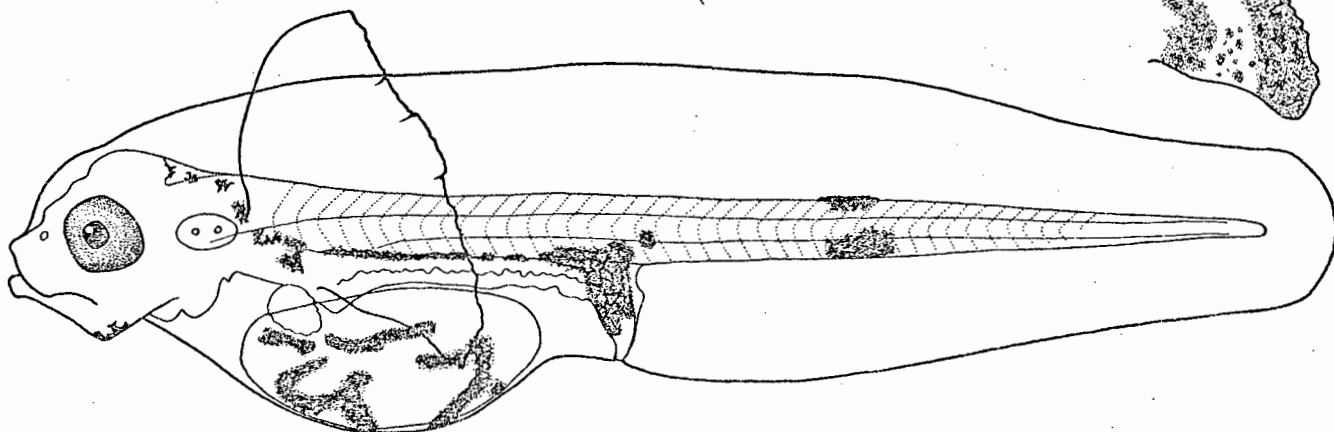
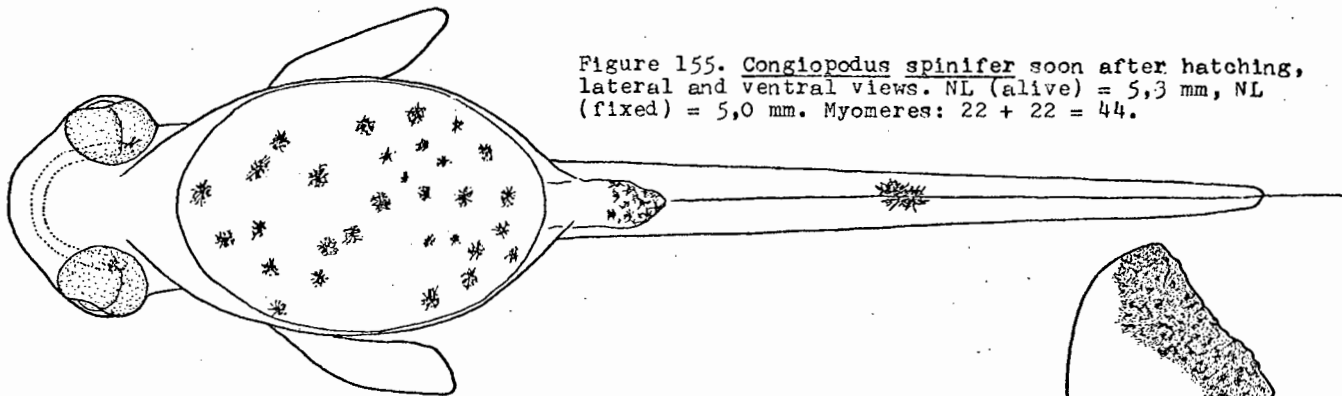


Figure 156. Congiopodus spinifer at 24 hours, lateral view and fin detail.
NL (alive) = 5,2 mm, NL (fixed) = 4,9 mm. Myomeres: 18 + 24 = 42.



noted by Gilchrist (1904). He did not mention any other differences between the eggs of the two species. If one can rely on Gilchrist's identifications of the ripe adults, and on Barnard's synonymies, one can only conclude that the eggs of the two horsefish species are very similar. Eggs have been described for one other congiopodid species, the southern pigfish of New Zealand (C. leucopaecilus). They also lack an oil globule, but are (on average) larger (1.93-2.18 mm) than those of the South African species (Robertson, 1975b). Eggs and early larvae of a related (but not included among the Congiopodidae by Hureau (1970)) species from Japan (Hypodytes rubripinnis) were figured by Mito (1963).

4.19.1 Congiopodus spinifer (spinenose horsefish) Figs. 154-158.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1904 (as Agriopus spinifer): egg, p. 144, fig. 49; embryo, p. 144, fig. 50.

Gilchrist, 1916 (as Agriopus spinifer): egg, p. 7; embryo, p. 7, fig. 4.

Gilchrist & Hunter, 1919 (as Agriopus spinifer): egg, p. 3, fig. 4; larva, p. 3, fig. 5.

Egg.

Fig. 154, table 3. Gilchrist (1903) reported that the ovarian egg (presumably of C. torvus) was covered by a "network of well-marked striations". He subsequently (1904) artificially fertilized C. spinifer eggs and followed their development for 4 days. He remarked on the "corrugated appearance" of the eggs, and provided an illustration on an egg to show the striated chorion. The present author can confirm the existence of striae on the chorion, but would hesitate to call them "well-marked". In fact, they are discernible only under special lighting conditions, and the same kind of markings are present on the chorion of a number of other species handled by Gilchrist.

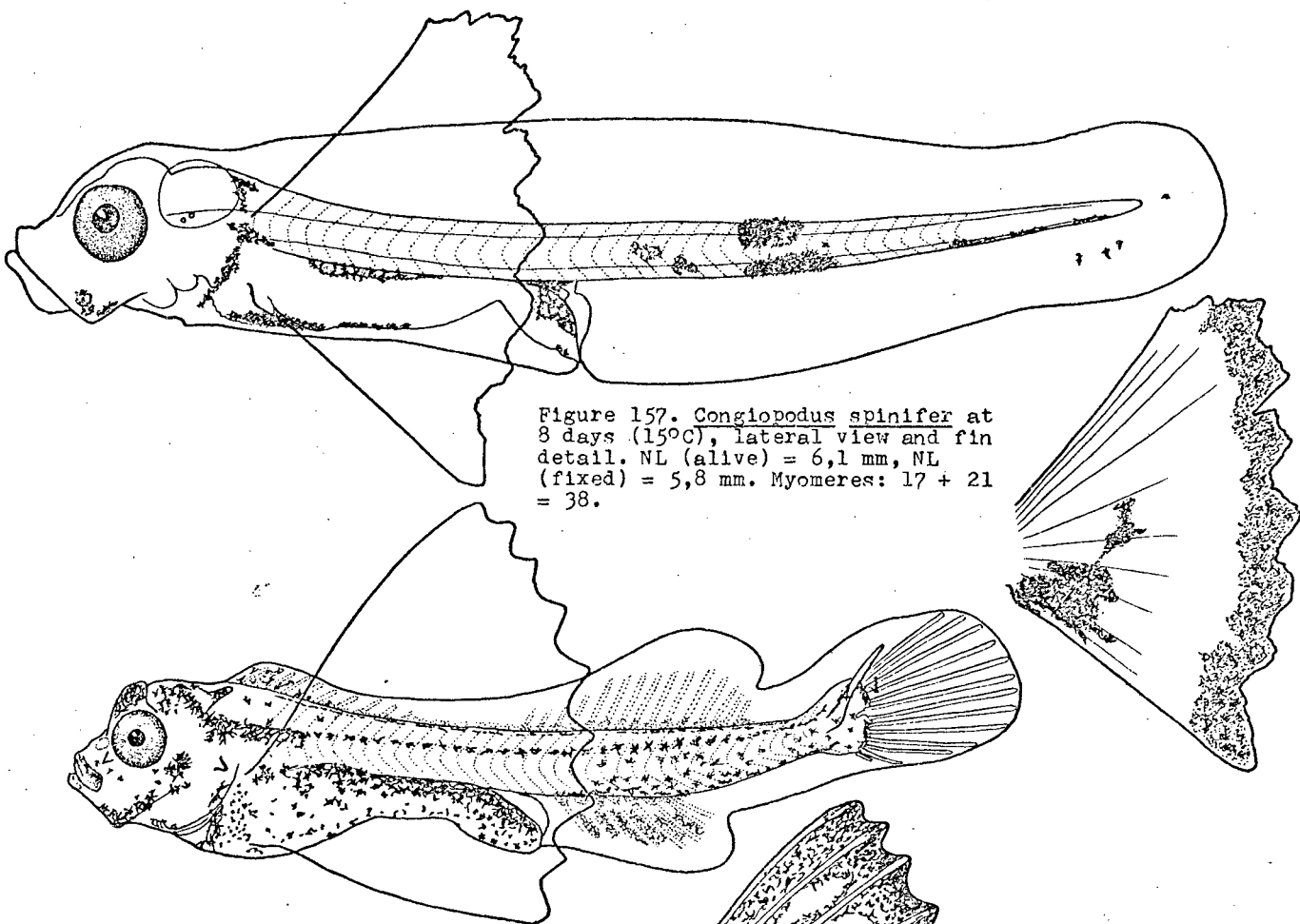


Figure 157. *Congiopodus spinifer* at 8 days (15°C), lateral view and fin detail. NL (alive) = 6,1 mm, NL (fixed) = 5,8 mm. Myomeres: 17 + 21 = 38.

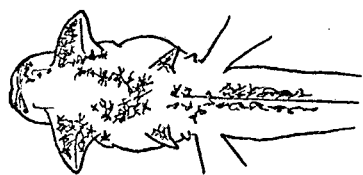


Figure 158. *Congiopodus spinifer* at 32 days (15°C), lateral view of larva, dorsal view of head, and fin detail. SL (alive) = 12,4 mm, SL (fixed) = 10,8 mm. Myomeres: 18 + 18 = 36.

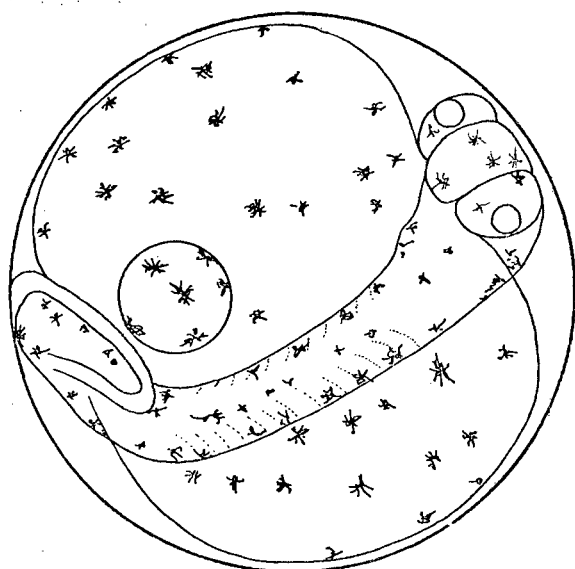
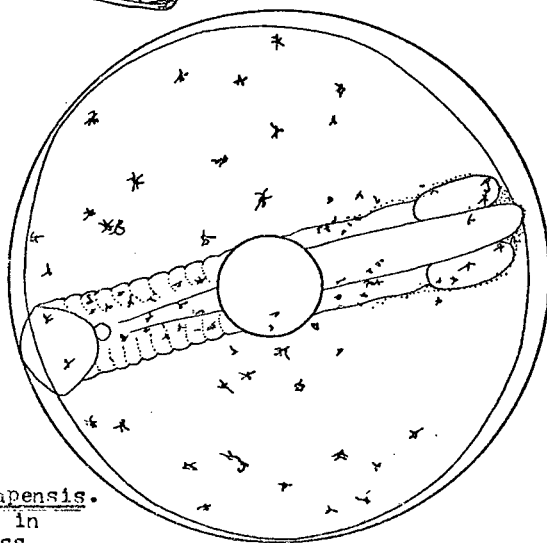


Figure 159. Two eggs of *Trigla capensis*. More advanced egg (left): 1,25 mm in diameter, oil globule 0,25 mm. Less developed egg (right): 1,33 mm in diameter, oil globule 0,25 mm.



Larva.

Figs. 155-158, table 3. Congiopodus passes through a unique and strikingly beautiful larval phase, characterized by the exaggerated development of the pectoral fins. No characters that might be useful in distinguishing larvae of the two South African Congiopodus species can be offered at this stage.

Meristics.

D XIX-XXI + 11-14, A 9-10 (Smith, 1965).

Geographic and seasonal distribution.

C. spinifer ranges from Walvis Bay to Delagoa Bay (Day et al. (1970). Gilchrist and Hunter (1919) reported C. spinifer eggs throughout the year in Table Bay. Assuming that all the congiopodid eggs collected during the present study were those of C. spinifer, the collection records (table 1) confirm year-round spawning for this species.

Bearing notes.

Incubation time (15°C): 206 ± 10 h (fig. 185.22). First-feeding was very successful on Brachionus; an experiment showed that Proales was not taken—no doubt because of its small size. Artemia nauplii were not offered as food, although a New Zealand species (C. leucopaecilus) is able to first-feed upon them (Robertson, 1974). Unlike C. leucopaecilus, C. spinifer cannot first-feed until about 36 h after hatching. Following metamorphosis (about 8 weeks post-hatch), growth slows: an individual kept for 2,5 years reached only 8,5 cm SL. During this period the fish was never seen to shed its skin—a phenomenon which Gilchrist (1914b) observed in specimen(s) kept in the old aquarium at St. James.

4.20 TRIGLIDAE

Four triglid species are recognized in waters around the Cape of Good Hope: Trigla capensis, Trigla kumu, Trigla queketti, and Trigloporus africanus. No triglids were reared through metamorphosis during this study and there is some

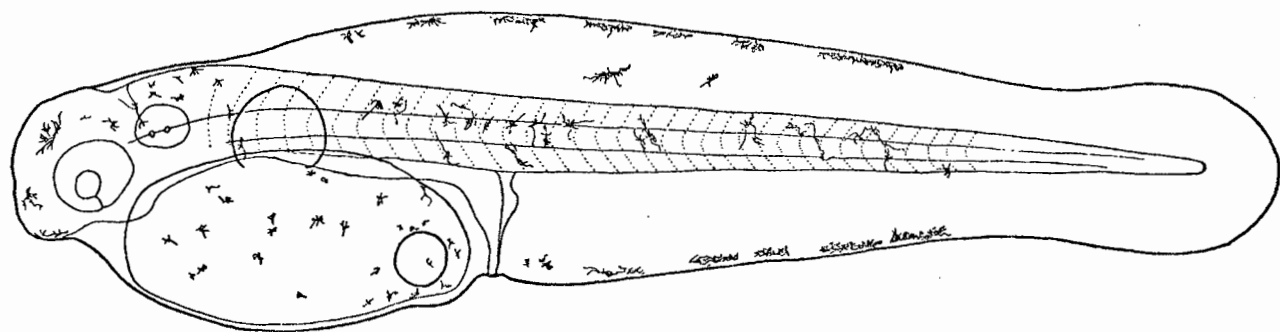


Figure 160. *Trigla capensis* soon after hatching. lateral and ventral views. NL (alive) = 3,7 mm, NL (fixed) = 3,6 mm. Myomeres: $13 + 23 = 36$.

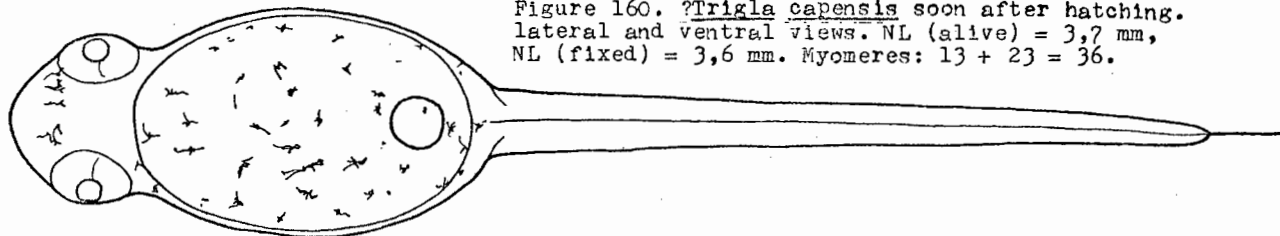


Figure 161. *Trigla capensis* at 2 days (15°C), lateral view and fin detail. NL (alive) = 4,0 mm, NL (fixed) = 3,5 mm. Myomeres: $11 + 25 = 36$.

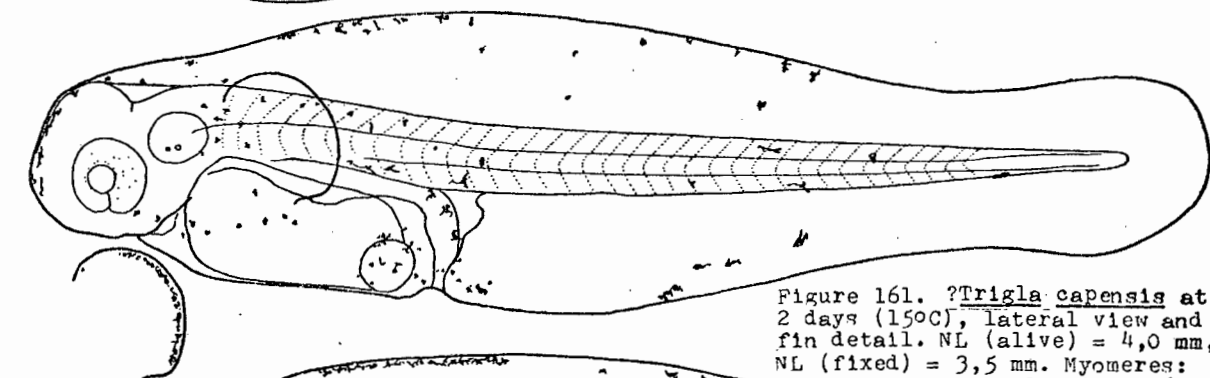


Figure 162. *Trigla capensis* at 4 days (15°C), lateral view and fin detail. NL (alive) = 4,3 mm, NL (fixed) = 4,1 mm. Myomeres: $9 + 26 = 35$.

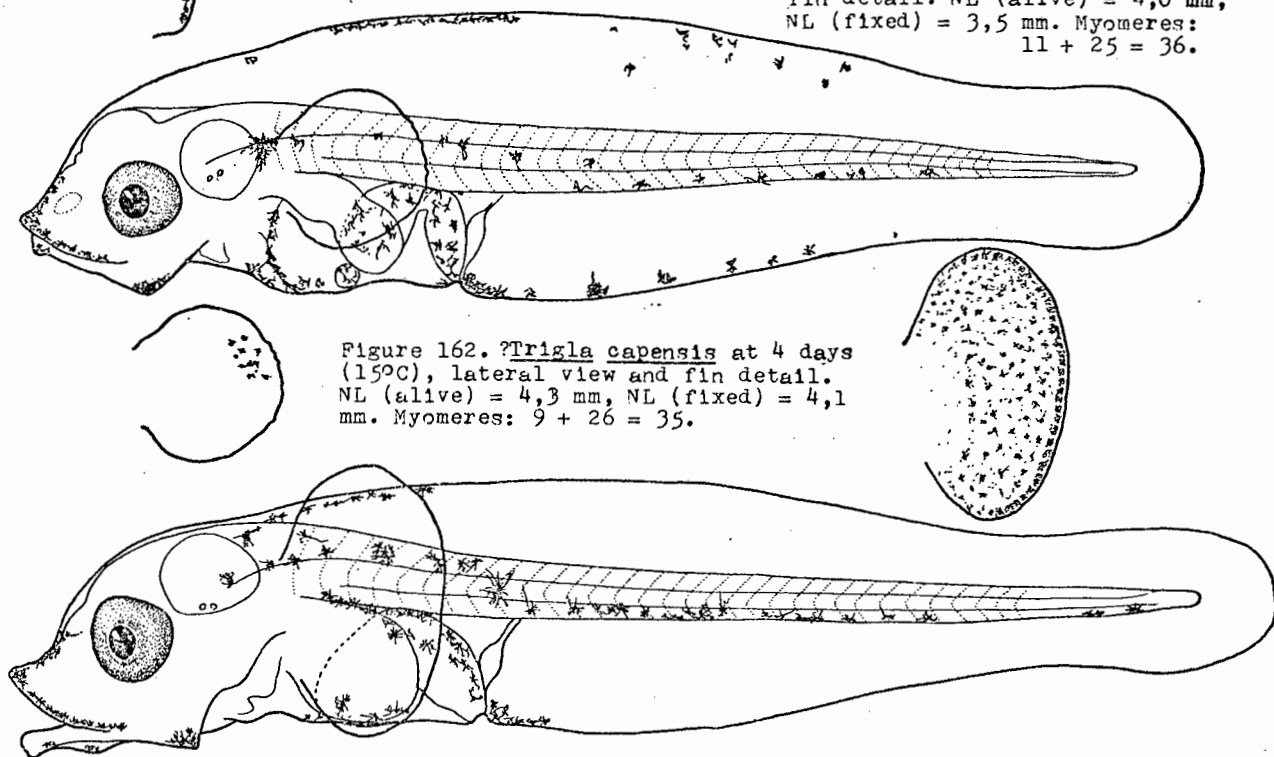


Figure 163. *Trigla capensis* at 8 days (15°C), lateral view and fin detail. NL (alive) = 4,4 mm, NL (fixed) = 4,2 mm. Myomeres: $9 + 24 = 33$.

doubt as to the identity of the eggs and larvae described below. They have been tentatively referred to Trigla capensis on the grounds that it is the more abundant of the four species. The wide size-range of triglid eggs encountered here (1,16-1,40 mm) suggests that more than one species is involved. Early stages of Trigla kumu (Mito, 1963; Robertson, 1975b) and, apparently, Trigla capensis (as Trigla kumu, see references below) have been described, but the descriptions do not permit a clear-cut distinction. There is a need for a comparison of material from artificial fertilization of identified parent stock of all four species.

4.20.1 ?Trigla capensis (Cape gurnard) Figs. 159-164.

Previous descriptions of eggs and/or larvae.

Gilchrist, 1903 (as Trigla kuma): egg, p. 190, fig. 14; larva, p. 190, fig. 15.

Gilchrist, 1916 (as Trigla kumu): egg, p. 7, fig. 3; larva, p. 7, fig. 3.

Gilchrist & Hunter, 1919 (as Trigla kumu): egg, p. 3, fig. 1; larva, p. 3, figs. 2-3.

(According to Barnard (1925-1927: 940) Gilchrist identified Trigla capensis as T. kumu.)

Egg.

Fig. 159, table 3.

Larva.

Figs. 160-164, table 3.

Meristics.

Trigla capensis: D VIII-IX + 15-16, A 15-16 (Smith, 1965).

Geographic and seasonal distribution.

T. capensis ranges from near Angola (18°S) (Trunov & Malevanyy, 1974) to Natal (Smith, 1965). Eggs were taken on both sides of the Cape Peninsula all year round, with no obvious peaks. Two reports on the reproductive biology of this species have appeared; both provide information on the seasonal frequency of females with ripe ova. Trunov &

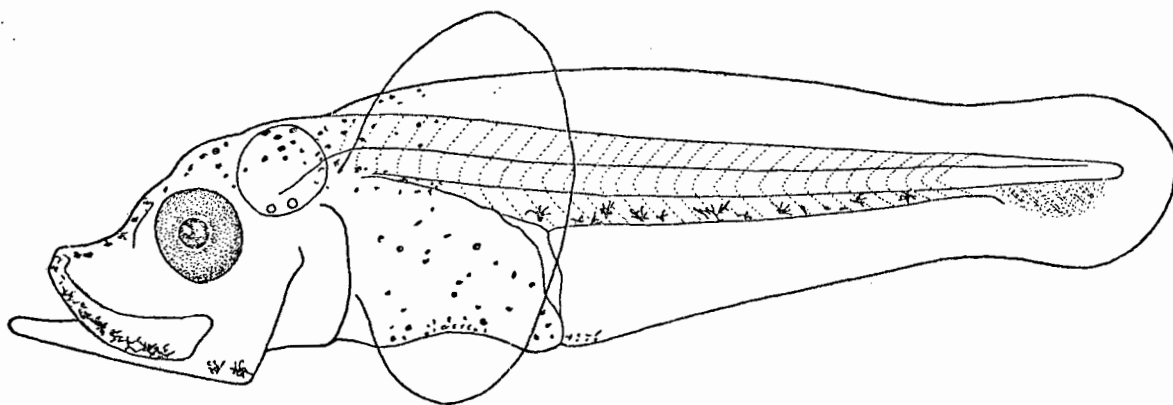


Figure 164. *Trigla capensis* at 16 days (15°C), lateral and dorsal views and fin detail. NL (alive) = 7,1 mm, NL (fixed) = 6,2 mm. Myomeres: 11 + 21 = 32.

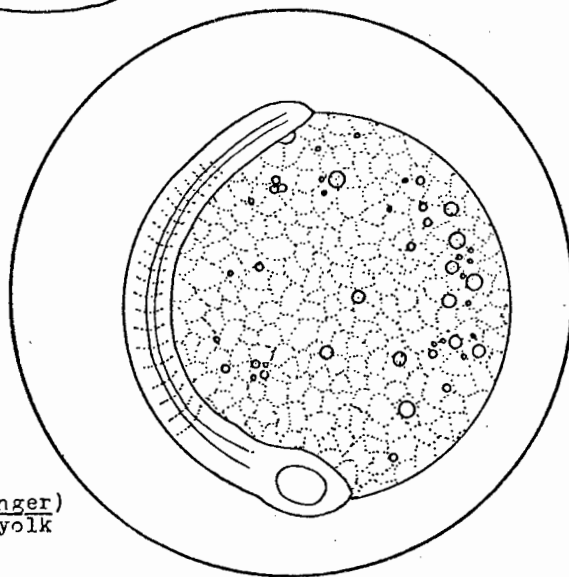
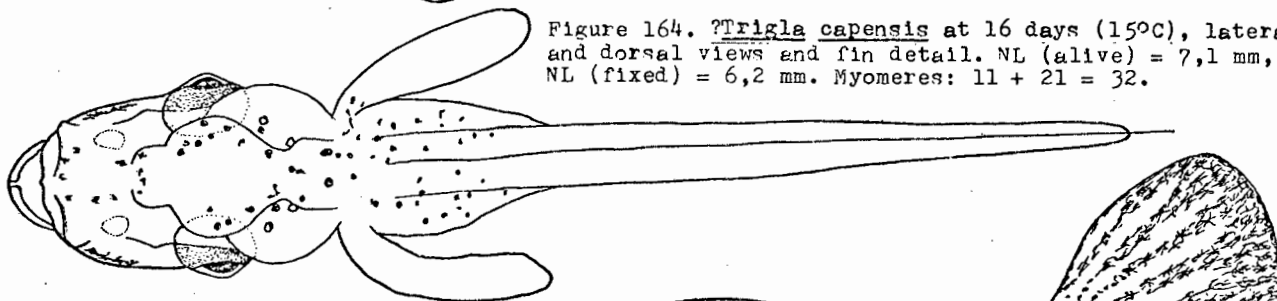


Figure 165. Species 6 (?Conger) egg. 2,63 mm in diameter, yolk diameter 1,80 mm.

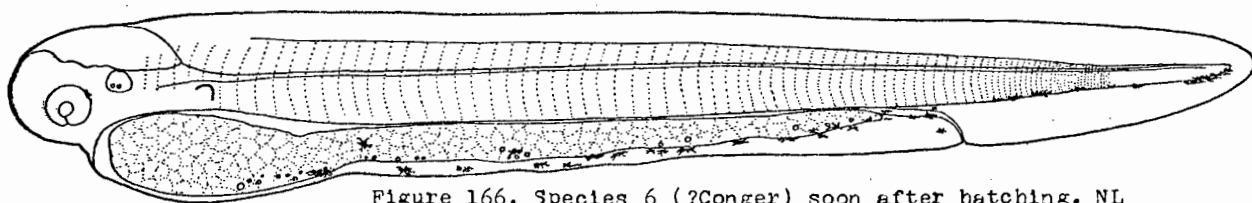


Figure 166. Species 6 (?Conger) soon after hatching. NL (alive) = 8,4 mm, NL (fixed) = 7,6 mm. Myomeres: 60 + ca. 50.

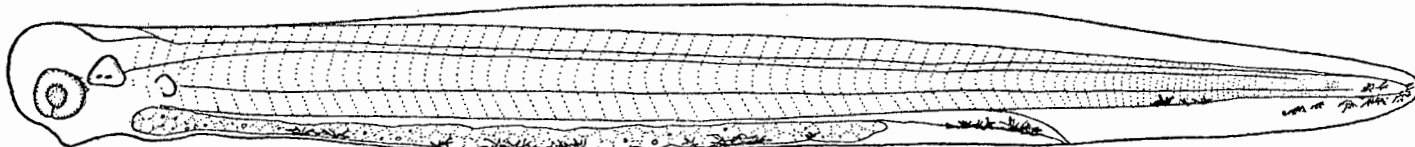


Figure 167. Species 6. (?Conger) at 4 days (15°C). NL (alive) = 9,4 mm, NL (fixed) = 8,5 mm. Myomeres: 59 + ca. 50.

Malevanyy (1974) concluded that spawning takes place off Namibia throughout the year, but reaches a height during the warmest period (December-March). Hecht (1977) suggested that T. capensis off the eastern Cape Province spawns twice during the period November-January, and again in March-April. The specimens that Gilchrist (1903) artificially fertilized were taken in False Bay in December.

Bearing notes.

Incubation time (all triglid eggs) at 15°C: 110 ± 10 h (fig. 185.24). Incidence of first-feeding (Brachionus) was consistently high (90%) between the ages of about 100 h and about 180 h post-hatch during 4-h feeding tests. Only one larva approached metamorphosis, however; the specimen was partially consumed by a newly-metamorphosed stomatopod that the author unwittingly placed in the tank.

4.21 CONGRIDAE

Day et al. (1970) recorded only two anguilliform species from False Bay: the congrid, Gnathophis capensis, and the ophichthid, Ophisurus serpens. Eggs of both species have been described, the former by Gilchrist (1904, as Species XX) and Castle (1969), the latter by Grassi (1913). The apode eggs collected during the present study are attributable to neither of these species: G. capensis eggs lack oil globules; O. serpens yolk-sac larvae have about 88 pre-anal myomeres (rather than about 60). The eggs are tentatively identified as those of the Cape conger.

4.21.1 Species 6 ?Conger wilsoni (Cape conger) Figs. 165-168.

Previous descriptions of eggs and/or larvae.

Castle, 1968: metamorphic larva, p. 697.

(Additional references are cited by Castle (1968).)

Egg.

Fig. 165, table 3. Its large size and wide perivitelline

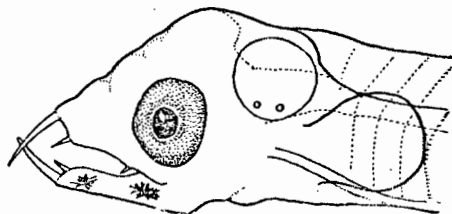
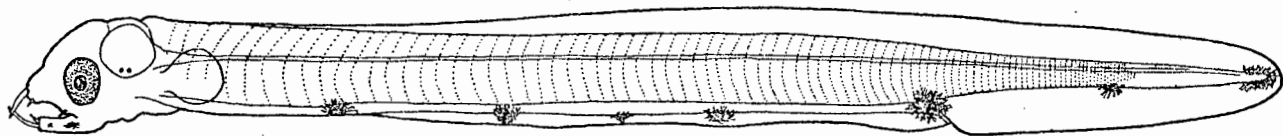


Figure 168. Species 6. (?Conger) at 8 days (15°C), lateral view and head detail. NL (alive) = 10,0 mm, NL (fixed) = 9,6 mm. Myomeres: 58 + ca. 50.

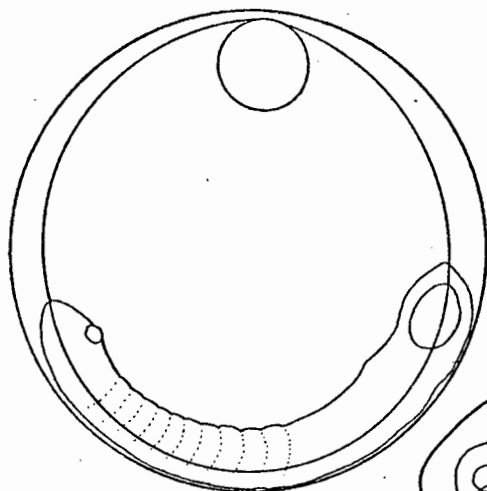


Figure 169. Species 7 egg. 0,90 mm in diameter, oil globule 0,17 mm.

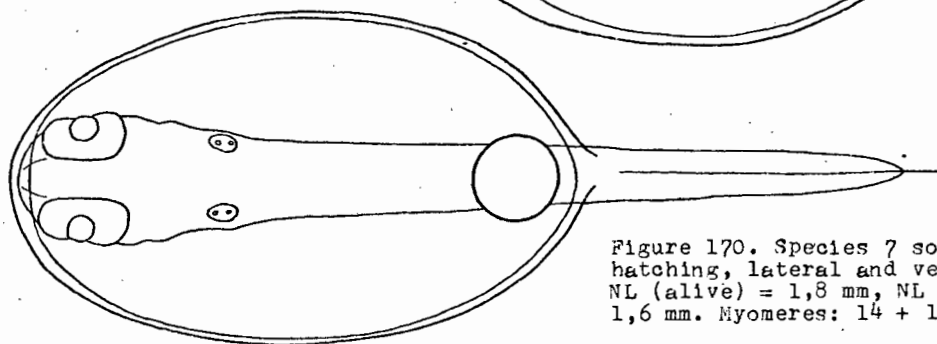
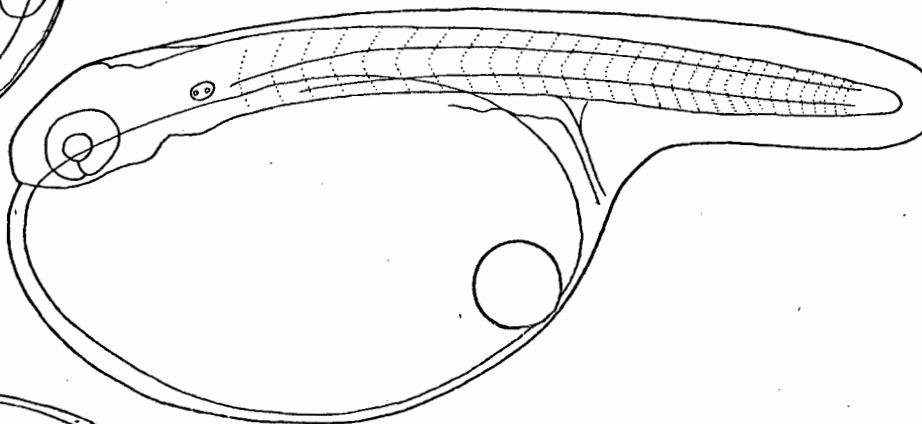


Figure 170. Species 7 soon after hatching, lateral and ventral views. NL (alive) = 1,8 mm, NL (fixed) = 1,6 mm. Myomeres: 14 + 16 = 30.

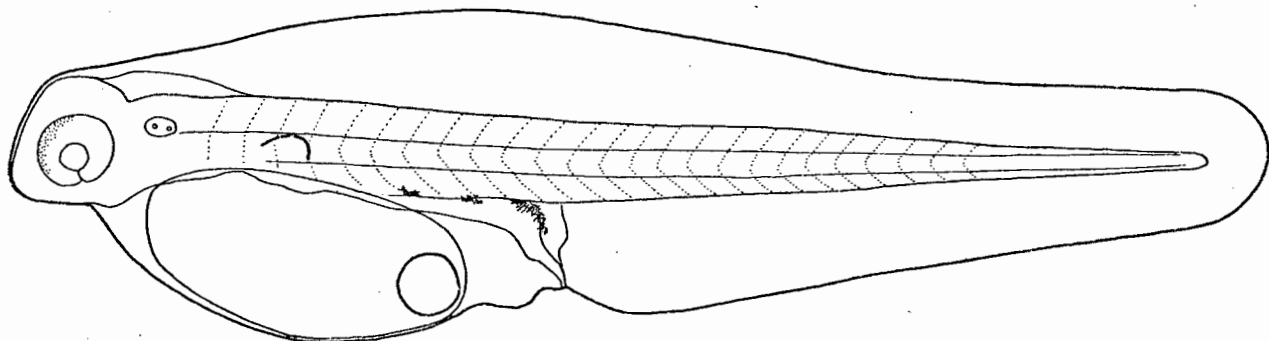


Figure 171. Species 7 at 2 days (15°C). NL (alive) = 2,7 mm, NL (fixed) = 2,4 mm. Myomeres: 12 + 14 = 28.

space immediately sets this egg apart from all others described here. The presence of ca. 5-35 oil globules distinguishes it from the egg of Gnathophis capensis. The author cannot distinguish it (by size or globules) from the egg described as Ophisurus serpens by Grassi (1913).

Larva.

Figs. 166-168, table 3.

Meristics.

Metamorphic larvae of C. wilsoni have $52-59 + 79-93 = 138-145$ myomeres. The adult has a vertebral count of $49-50 + 90-92 = 140-142$ (Castle, 1968).

Geographic and seasonal distribution.

C. wilsoni is known from the Cape to Delagoa Bay (Smith, 1965: as C. conger); the type locality is Australia. Kana-zawa (1958) and Castle (1968) provided evidence that its range may extend to Japanese waters, under the name C. jordani. Eggs were taken on three occasions, once in Hout Bay in November, twice in Fish Hoek Bay in March (table 1).

Rearing notes.

Of the 40 eggs of this species collected, 24 hatched within the first 156 h, one hatched almost 3 days later in an advanced state (eye pigmentation appeared the following day), one was kept out for illustrating, and the other 14 died in the shell. The distribution of incubation times from blastodisc stage to hatching indicates an embryonic life (at 15°C) of slightly over 6-6,5 days (fig. 185.26). Mortality was high in the yolk-sac stage, and only 5 survived to 8 days post-hatch. These were placed in rearing tanks with Brachionus and Proales, but virtually no feeding took place. On the following day, two of the larvae were seen to have a single whitish particle in the gut, probably food, but this was not confirmed by microscopic examination. All larvae died over the subsequent 48 h.

4.22 EGGS AND LARVAE OF UNKNOWN AFFINITIES

4.22.1 Species 7 Figs. 169-173.

Previous descriptions of eggs and/or larvae.

?Gilchrist, 1904 (as Species XII): egg, p. 134; larva, p. 134.

Egg.

Fig. 169, table 3. The absence of any pigment on the late embryo distinguishes the egg from those of a number of other species (particularly sparids) with which it might easily be confused.

Larva.

Figs. 170-173, table 3. The larva is characterized by an absence of all pigment for the first 24-36 h after hatching. Heavy black pigmentation subsequently forms over the gut.

Geographic and seasonal distribution.

These eggs were taken on the Atlantic side of the Cape Peninsula only, during the months of September and October. (table 1). Gilchrist (1904) netted what appears to be the same species in False Bay in November.

Rearing notes.

Incubation time (15°C): 54 ± 10 h (fig. 185.27). First-feeding was not successful on Brachionus and only rarely on Proales. No larvae survived to the 16th day post-hatch.

4.22.2 Species 8 Figs. 174-177.

Previous descriptions of eggs and/or larvae.

Gilchrist & Hunter, 1919 (as Merluccius capensis): egg, p. 6, figs. 10-11; larva, p. 6, figs. 12-13.

Egg.

Fig. 174, table 3. In size, the egg is similar to that of Trigla capensis. Near hatching, it may be distinguished by the absence of yellow pigment and greater density of black pigment.

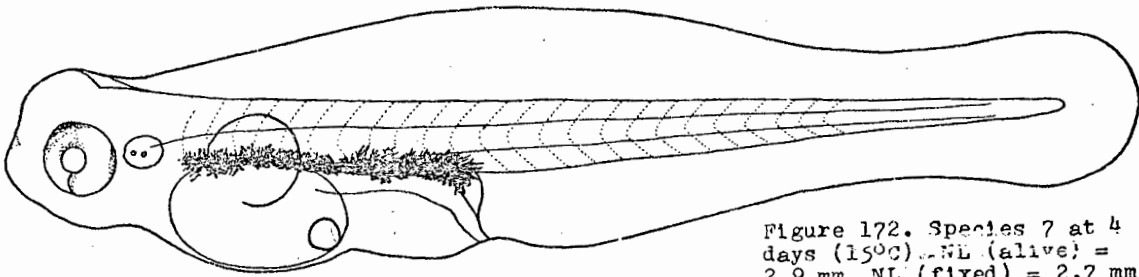


Figure 172. Species 7 at 4 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,7 mm. Myomeres: 12 + 13 = 25.

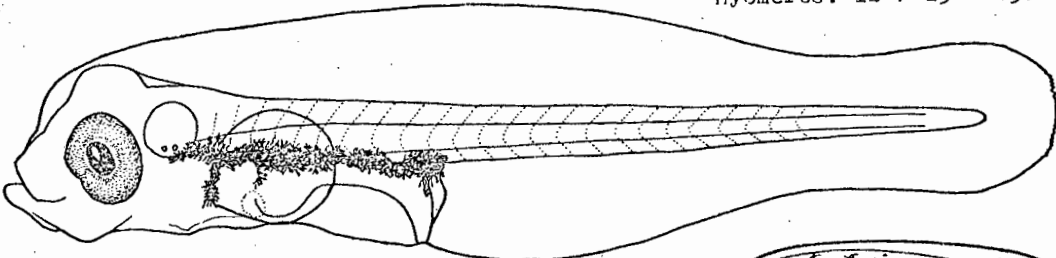


Figure 173. Species 7 at 8 days (15°C). NL (alive) = 3,0 mm, NL (fixed) = 2,8 mm. Myomeres: 10 + 15 = 25.

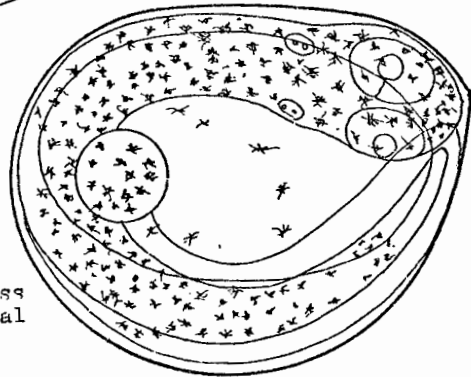


Figure 174. Species 8 egg in process of hatching. Diameter when spherical was 1,28 mm, oil globule 0,28 mm.

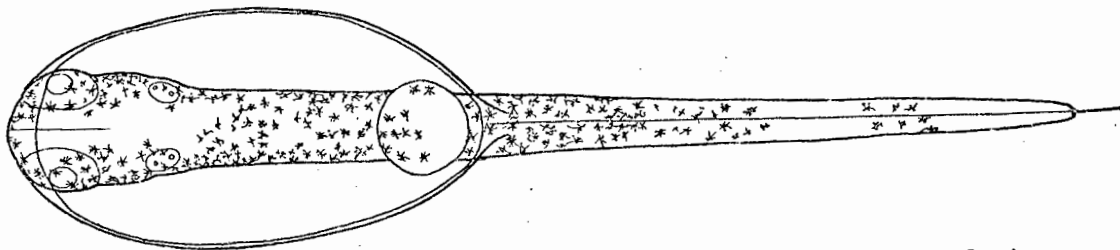
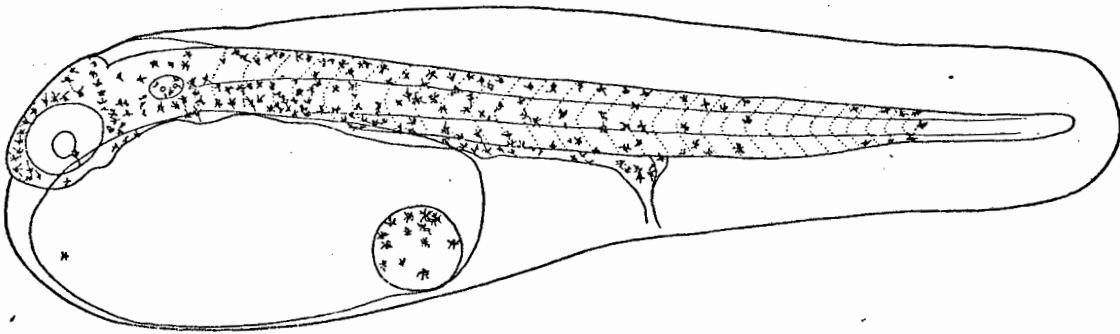


Figure 175. Species 8 soon after hatching, lateral and ventral views. NL (alive) = 3,2 mm, NL (fixed) = 2,7 mm. Myomeres: 17 + 13 = 30.

Larva.

Figs. 175-177, table 3. As in Liza richardsoni, the anus is situated in the posterior half of the body and the pre-anal myomeres outnumber the post-anal. The absence of yellow pigment and the presence of uniformly dense black pigment distinguishes Species 8 from L. richardsoni.

Geographic and seasonal distribution.

The egg was taken in small numbers from July to October, inclusive, on both sides of the Cape Peninsula.

Bearing notes.

Insufficient data were available to establish the incubation time of this species. The two eggs that required the longest incubation hatched 72-84 h after collection (fig. 185.28). First-feeding incidence was 100% (n=7) on Brachionus but no larvae survived beyond three weeks post-hatch.

4.22.3 Species 9 Figs. 178-181.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Fig. 178, table 3. The most striking feature of the advanced egg of this unidentified species is the heavy yellow pigment covering the oil globule, as well as parts of the body. The combination of chorion and oil globule size and yolk vesiculation distinguishes the egg from all others described here.

Larva.

Figs. 179-181, table 3.

Geographic and seasonal distribution.

Eggs of Species 9 were taken in False Bay from October to February, inclusive. None were found in collections from the Atlantic (table 1).

Bearing notes.

Incubation time (15°C): 62 ± 10 h (fig. 185.29).

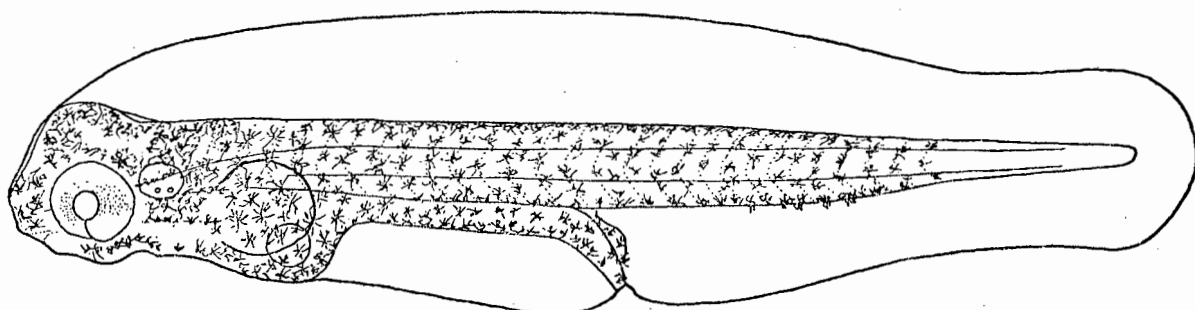


Figure 176. Species 8 at 4 days (15°C). NL (alive) = 4,2 mm, NL (fixed) = 3,8 mm. Myomeres: 16 + 13 = 29.

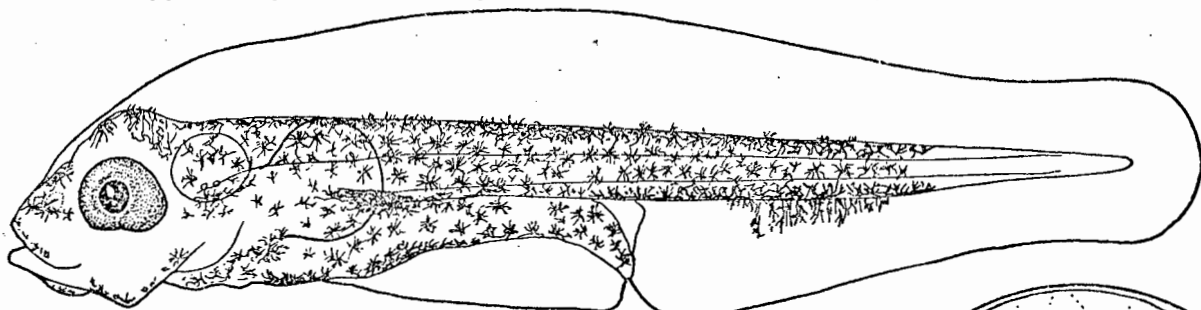


Figure 177. Species 8 at 8 days (15°C). NL (alive) = 4,5 mm, NL (fixed) unavailable, specimen damaged prior to fixing. Myomeres: not visible in live specimen, masked by pigment.

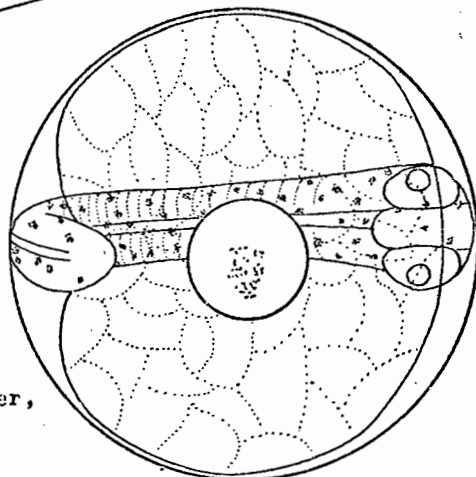


Figure 178. Species 9 egg. 0,94 mm in diameter, oil globule 0,24 mm.

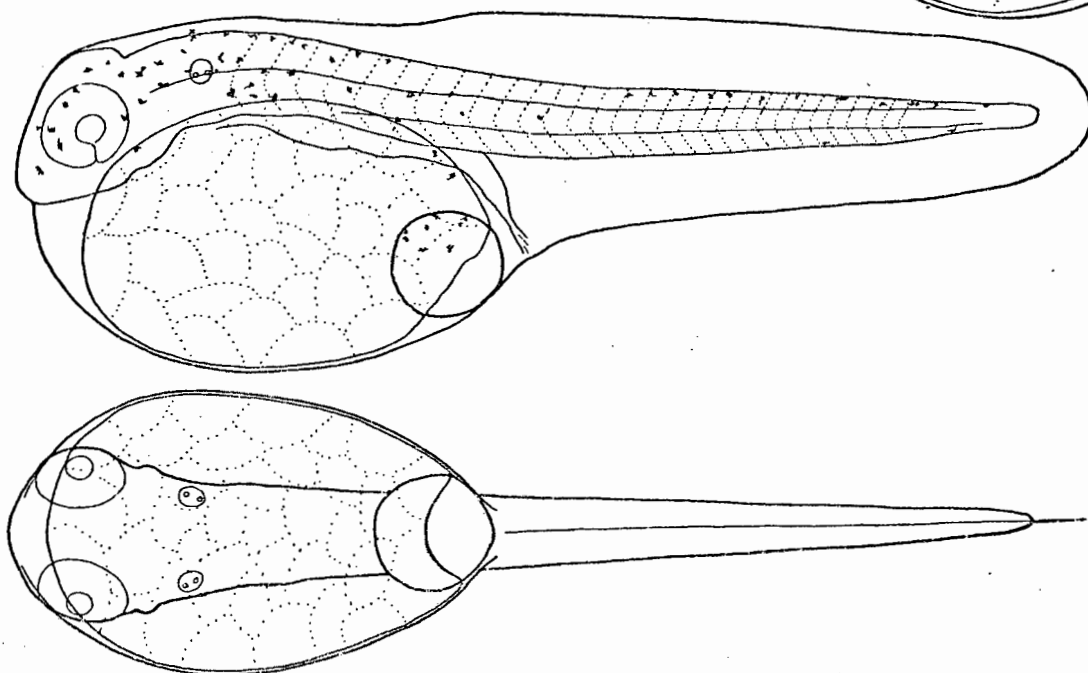


Figure 179. Species 9 soon after hatching, lateral and ventral views. NL (alive) = 2,2 mm, NL (fixed) unavailable, specimen damaged prior to fixing. Myomeres: 11 + 20 = 31.

First-feeding was sporadic on both Brachionus and Proales; rearing attempts were unsuccessful.

4.22.4 Species 10 Figs. 182-183.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Not recognized. Judging from the size of the newly-hatched larva, the egg diameter is likely to be in the range 0,85-0,95 mm. There is a single oil globule in the newly-hatched larva of 0,23-0,24 mm in diameter.

Larva.

Figs. 182-183, table 3. The larva at hatching is unique among those described here by virtue of its pigmentation: black and orange spots scattered on the body.

Geographic and seasonal distribution.

The eggs were taken in False Bay in January and February (table 1).

Bearing notes.

The yolk-sac larvae appeared to be exceptionally sensitive to entrapment on the surface film. None survived to first-feeding.

4.22.5 Species 11 Fig. 184.

Previous descriptions of eggs and/or larvae.

None.

Egg.

Not recognized. Judging from the size of the larva at hatching, the egg is likely to be in the range 0,70-0,80 mm. The oil globule is the newly-hatched larva measured 0,18 mm.

Larva.

Fig. 184, table 3. The pigmentation and small size of the newly-hatched larva renders it unique among those encountered during this study.

Geographic and seasonal distribution.

A single egg was taken: False Bay in December.

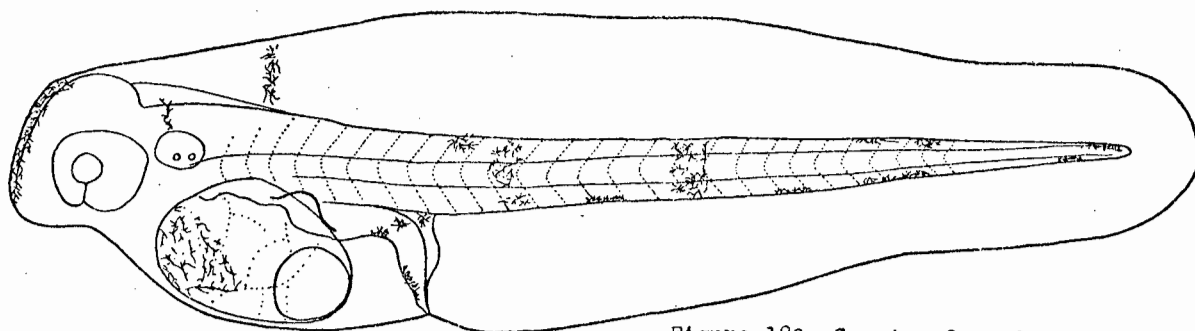


Figure 180. Species 9 at 2 days (15°C). NL (alive) = 3,0 mm, NL (fixed) = 2,8 mm. Myomeres: $9 + 19 = 28$.

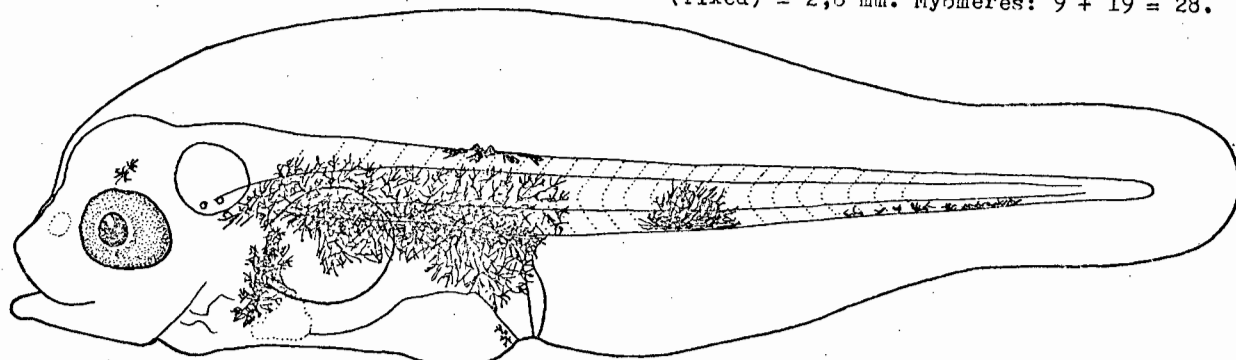


Figure 181. Species 9 at 8 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,7 mm. Myomeres: $10 + 16 = 26$.

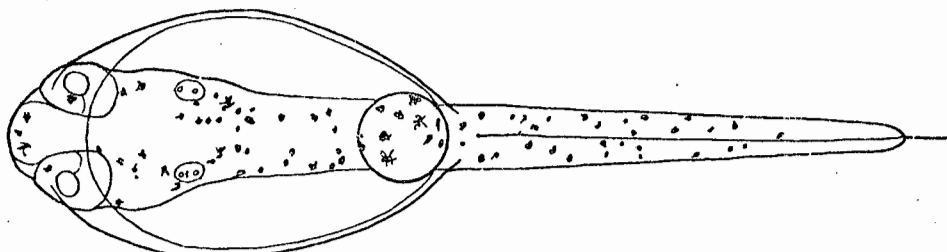
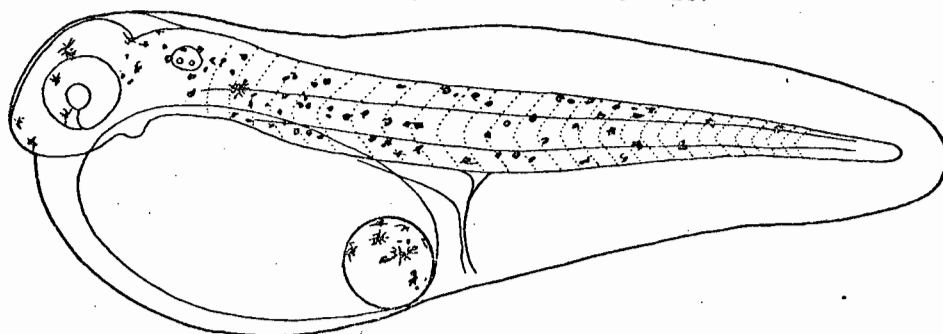


Figure 182. Species 10 soon after hatching, lateral and ventral views. NL (alive) = 2,3 mm, NL (fixed) = 2,0 mm. Myomeres: $12 + 17 = 29$.

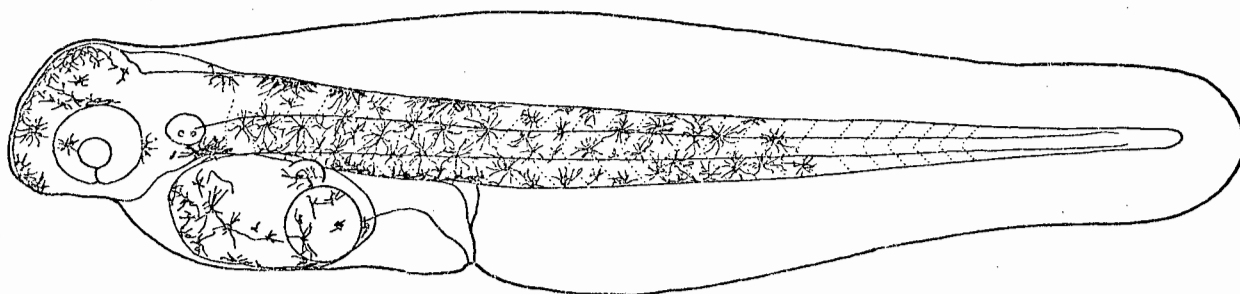


Figure 183. Species 10 at 2 days (15°C). NL (alive) = 2,9 mm, NL (fixed) = 2,6 mm. Myomeres: $10 + 17 = 27$.

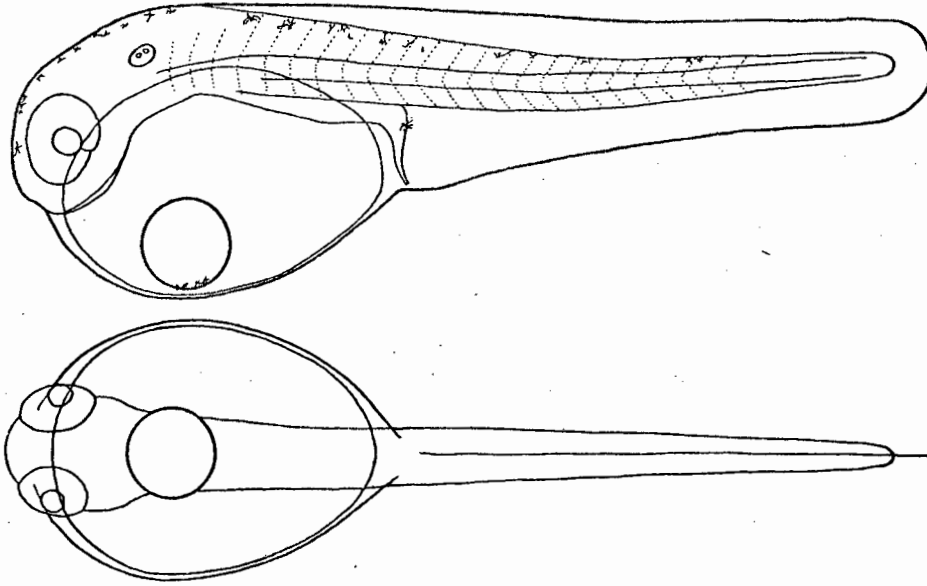


Figure 184. Species 11 soon after hatching, lateral and ventral views.
NL (alive) = 1,8 mm, NL (fixed) = 1,6 mm. Myomeres: 10 + 15 = 25.

Table 3. Summary of salient characters of eggs and early larvae. Only species encountered in the plankton during the present study have been included. Eggs are arranged in order of decreasing size.

diameter of oil globules	number of oil globules	diameter of oil globule	perivitelline space	yolk texture	chorion texture	incubation time (#10h) at 15°C	NL (alive) at hatching	position of oil globule at hatching	position of annus at first-feeding	species	page no.	figures
44-2,72	5-35	variable	wide ¹	segmented	smooth	>150	ca. 7,0-9,0	dispersed	posterior	? <u>Conger wilsoni</u>		
40-2,45	0	-	narrow	hazy	smooth	long	ca. 8,0-9,0	-	med/post	<u>Scomberesox saurus</u>	144	-
30-2,10	1	0,25-0,26	narrow	segmented	see text	?	ca. 3 mm	usually ventral	median	<u>Maurolicus muelleri</u>	143	-
20-2,00	0	-	narrow	hazy	smooth	206	5,2-6,0	-	median	<u>Congloporodus spinifer</u>	234	154-158
30-1,62	>100	variable	narrow	clear	smooth	?	3,3-3,7	dispersed	med/ant	Species 2 (<u>Soleidae</u>)	173	53-55
40-1,80	1	0,13-0,17	wide ²	segmented	smooth	ca. 60 ³	3,8-4,3	usually vent/post	posterior	<u>Sardinops ocellata</u>	140	2-3
33-1,45	0	-	narrow	segmented	smooth	70	4,5-5,6	-	posterior	<u>Brumeus teres</u>	138	-
33-1,45	1	0,30-0,35	narrow	segmented	smooth	?	3,7-4,3	anterior	med/post	Species 4 (<u>?Seriola</u>)	189	82-84
28-1,44	>100	variable	narrow	hazy/olear	smooth	100	3,2-3,6	dispersed	med/ant	<u>Synaptura klein</u>	169	46-52
33-1,35	1	0,26-0,28	narrow	clear	smooth	?	3,1-3,4	posterior	median	Species 8	243	174-177
6-1,40	1 (2-5)	0,22-0,26	narrow	clear	smooth	110	3,5-3,9	posterior	anterior	? <u>Trigla capensis</u>	238	159-164
0-1,60, 55-0,65	0	-	narrow	segmented	smooth	ca. 70 ⁴	2,5-3,1	-	posterior	<u>Engraulis capensis</u>	142	4-5
8-1,30	1	0,09-0,11	narrow	clear	smooth	106	3,8-4,3	ventral	median	<u>Xiphidius capensis</u>	159	23-28
0-1,28	1	0,21-0,24	narrow	clear	smooth	90	2,3-2,9	posterior	anterior	<u>Pterosmaris axillaris</u>	192	85-92

Notes: 1. Yolk diameter is ca. 1,80 mm.
2. Yolk diameter is 0,88-1,00 mm.
3. After King, 1977a
4. After King et al., 1978

Table 3. (cont.)

number of oil globules	diameter of oil globule	perivitelline space	yolk texture	chorion texture	incubation time (-10h) at 15°C	NL (alive) at hatching	position of oil globule at hatching	position of anus at first-feeding	species	page no.	figures
08-1,20	0	narrow	clear	smooth	?	2,1-2,4	-	anterior	<u>Coccotropsis</u> <u>kymnoderma</u>	223	135-141
06-1,22	1	narrow	clear	smooth	82	2,6-3,1	posterior	anterior	<u>Pachymetopon</u> <u>blochi</u>	213	115-122
04-1,15	1	narrow	clear	smooth	86	3,3-3,8	anterior	median	Species 3 { <u>Cheilodactylus</u> }	184	69-76
00-1,08	1	narrow	clear	smooth	?	2,3-3,0	posterior	anterior	<u>Physiculus</u> <u>capensis</u>	150	12-15
09-1,20 0,94-1,05	1	narrow	clear	smooth	80	4,6-5,2	ventral	anterior	Species 1 (<u>Carapidae</u>)	156	19-22
98-1,05	1	narrow	clear	smooth	74	2,2-2,7	posterior	anterior	Species 5 (<u>Sparidae</u>)	215	124-128
97-1,04	0	narrow	hazy	smooth	80	1,9-2,4	-	anterior	<u>Heteromycteris</u> <u>capensis</u>	166	39-45
95-1,05	1	narrow	clear	smooth	?	2,6-3,2	posterior	anterior	<u>Merluccius</u> <u>capensis</u>	153	16-18
94-1,03	1 (2-10)	narrow	clear	smooth	?	2,4-3,0	posterior	med/post	<u>Liza</u> <u>richardsoni</u>	221	129-134
91-1,02	1	narrow	clear	smooth	?	2,5-3,0	posterior	anterior	<u>Diplodus</u> <u>cervinus</u>	201	94-96
91-0,99	1	narrow	segmented	smooth	56	2,2-2,7	anterior	median	<u>Trachurus</u> <u>capensis</u>	187	77-81
90-0,99	1	narrow	segmented	smooth	?	2,0-2,4	posterior	med/ant	Species 9	245	178-181

Footnotes: 5. See text for dimensions reported by other authors.

Table 3. (cont.)

diameter of egg	number of oil globules	diameter of oil globule	perivitelline space	yolk texture	chorion texture	incubation time (±10h) at 15°C	NL (alive) at hatching	position of oil globule at hatching	position of anus at first-feeding	species	page no.	figures
90-0,96	1	0,16-0,18	narrow	clear	smooth	?	1,8-2,1	posterior	med/ant	Species 7	243	169-173
92-0,98 0,88-0,93	1	0,23-0,25	narrow	segmented	smooth	?	1,9-2,6	posterior	med/ant	<u>Helicolenus dactylopterus</u>	226	142-146
88-0,97	1	0,19-0,21	narrow	clear	smooth	74	2,3-2,8	posterior	anterior	<u>Diplodus sargus</u>	204	97-104
86-0,93	1	0,18-0,20	narrow	segmented	smooth	54?	1,4-2,2	vent/post	median	<u>Sebastichthys capensis</u>	229	147-153
85-0,95	1	0,23-0,24	narrow	clear	smooth	?	ca. 2,3	posterior	anterior?	Species 10	247	182-183
83-0,92	1	0,175-0,19	narrow	clear	smooth	74	1,8-2,3	posterior	anterior	<u>Lithognathus mormyrus</u>	209	106-114
80-0,90	12-20	variable	narrow	clear	smooth	80	1,7-2,1	posterior	anterior	<u>Austroglossus microlepis</u>	163	33-38
74-0,84	1 (2-5)	0,16-0,18	narrow	clear	smooth	96	2,0-2,4	posterior	med/ant	<u>Gaidropsarus capensis</u>	146	6-11
72-0,78	0	+	narrow	segmented	smooth	40	1,1-1,5	-	med/ant	<u>Paracallionymus costatus</u>	180	64-68
72-0,78	1	0,11-0,13	narrow	clear	smooth	45	1,9-2,5	posterior	med/ant	<u>Arnoglossus capensis</u>	161	29-32
70-0,91	2-16	variable	narrow	clear	smooth	62	1,2-1,8	variable	anterior	<u>Trulla capensis</u>	177	56-63
70-0,80	1	ca. 0,18	?	clear	?	?	ca. 1,6	ventral?	?	Species 11	247	184

5. INCUBATION PERIODS

After being sorted from the plankton, the eggs were placed in small numbered baskets (see Part 1 of this thesis) floating in the water table of a closed-circulation system. They were inspected at approximately 12-h intervals, and any larva that had hatched during the previous 12 h was identified (when possible), counted, and transferred to a larger numbered basket where it remained until first-feeding age. Each basket received only hatchlings from a single 12-h interval and the time of hatching (within 6 h) of any larva was therefore known. From the time-of-hatch and the time-of-collection, it was a simple matter to calculate the duration of the captive portion of the incubation period. When samples were large, an estimate of the duration of the entire incubation period could be attempted by assuming that those eggs with the longest incubation times were newly-spawned at point-of-collection. Error arising from delays between spawning and collection are more or less offset by errors arising from post-mature hatching.

Captive incubation times for 29 species are presented graphically in fig. 185. The author's estimates of total incubation time at 15°C for most of these species may be found in the text (under "rearing notes") and in table 3.

Figure 185. Distribution of post-collection incubation times (15°C) for 29 species. The logarithm of the number of eggs that hatched during each 12-h period after collection is plotted against the time interval between collection and hatching.

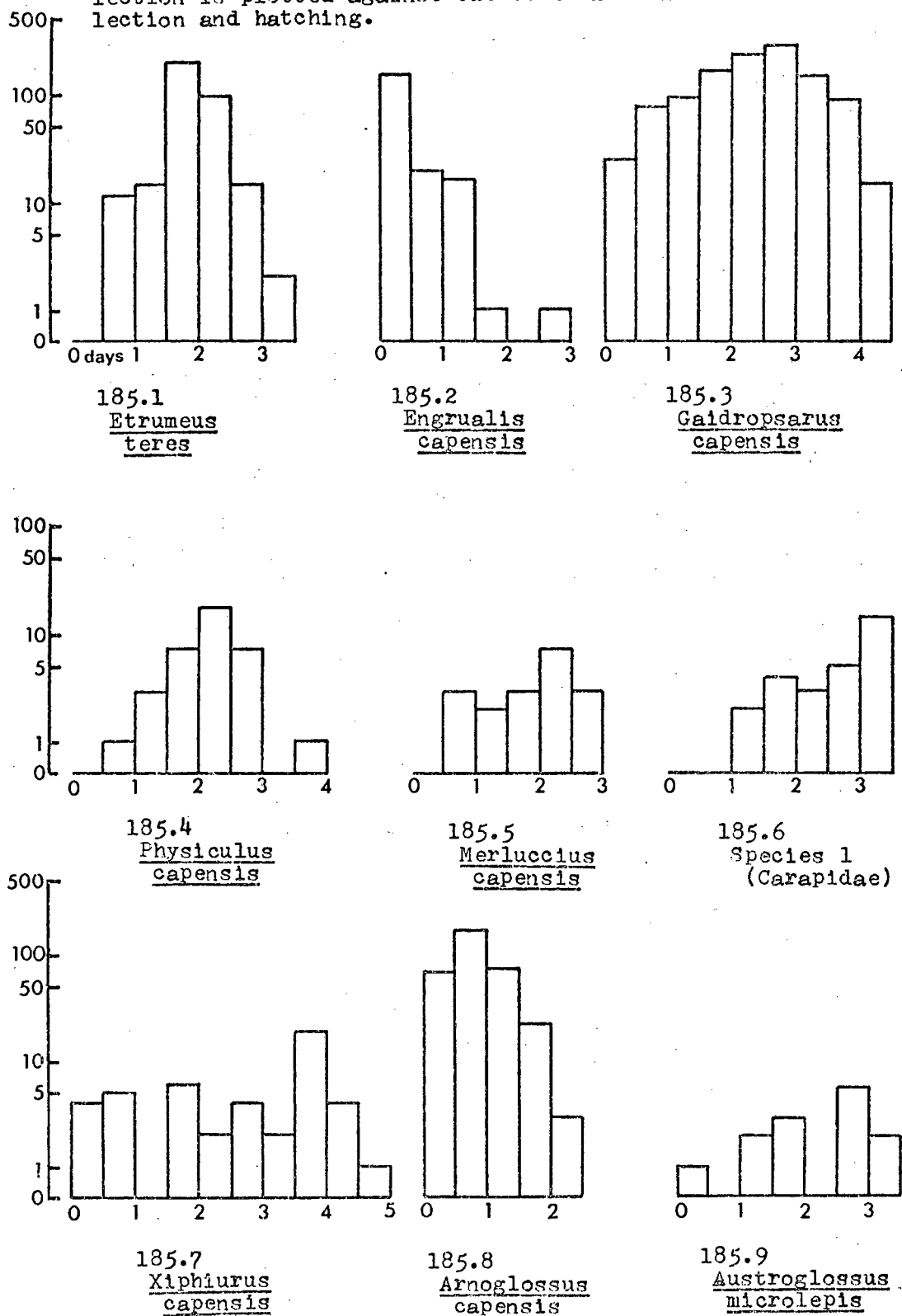
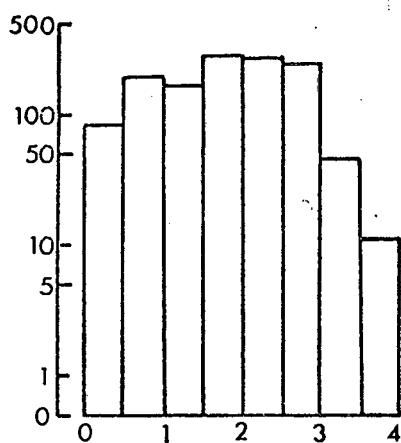
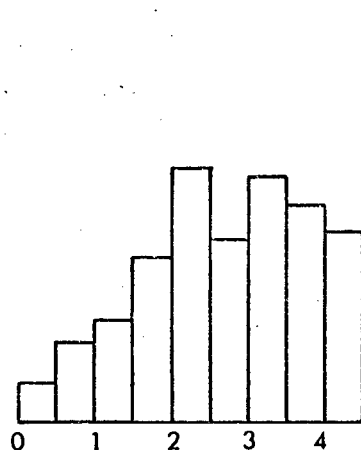


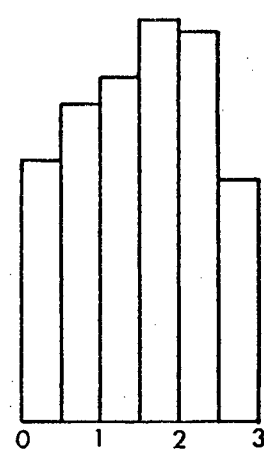
Fig. 185 (cont.)



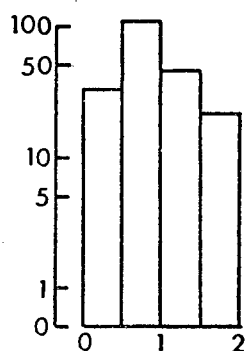
185.10
Heteromycteris
capensis



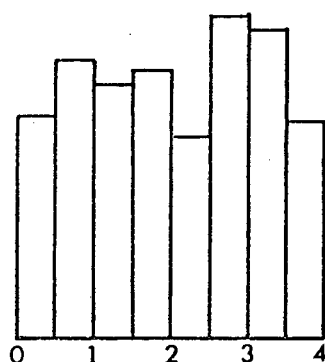
185.11
Synaptura
kleini



185.12
Trulla
capensis



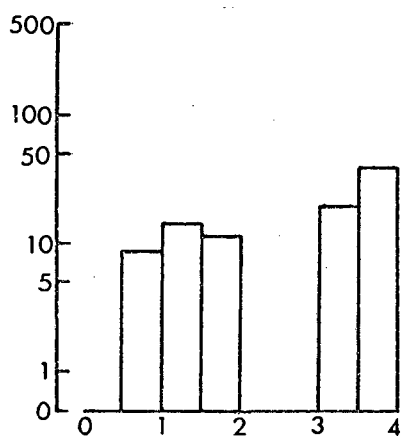
185.13
Paracallionymus
costatus



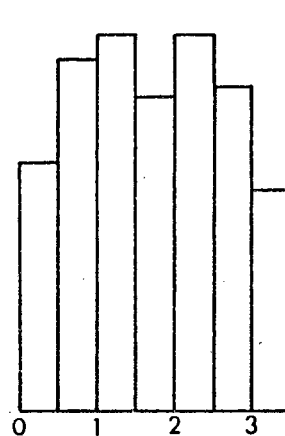
185.14
Species 3
(?Cheilodactylus)



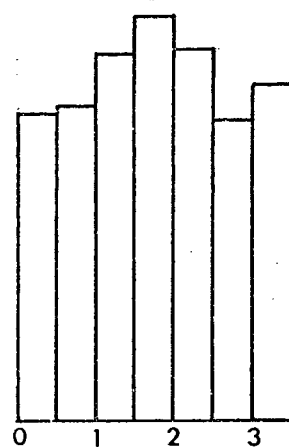
185.15
Trachurus
capensis



185.16
Pterosmaris
axillaris



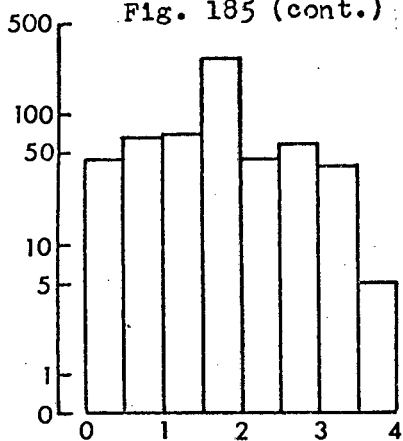
185.17
Diplodus
sargus



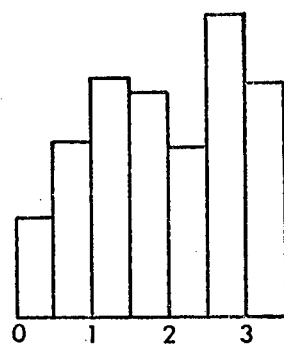
185.18
Lithognathus
mormyrus

Fig. 185 (cont.)

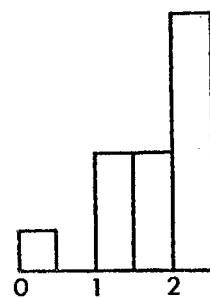
256



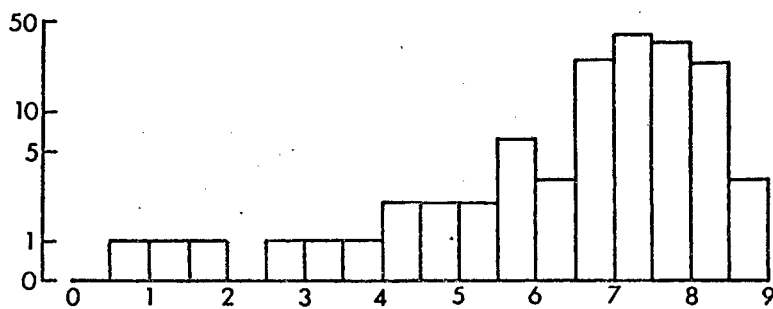
185.19
Pachymetopon
blochi



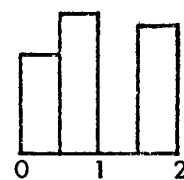
185.20
Species 5
(Sparidae)



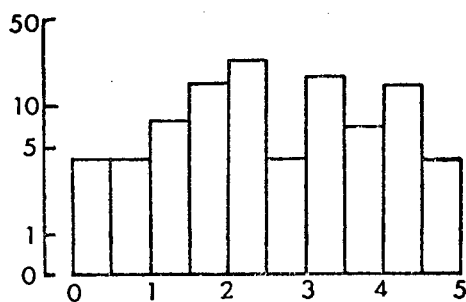
185.21
Sebastichthys
capensis



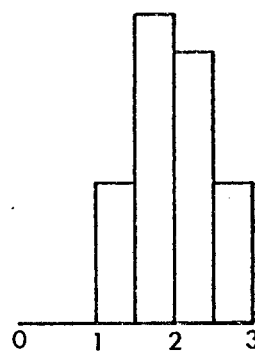
185.22
Congiopodus
spinifer



185.23
Coccotropsis
gymmoderma

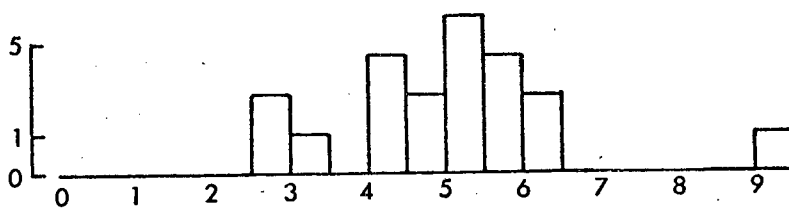


185.24
?Trigla
capensis

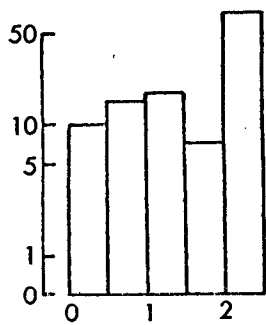


185.25
Helicolenus
dactylopterus

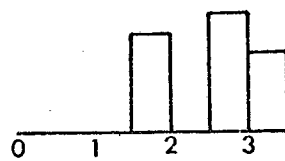
Fig. 185 (cont.)



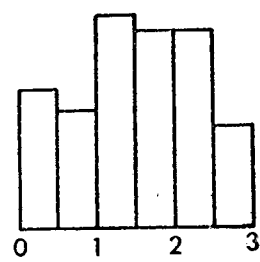
185.26
Species 6
(?Conger)



185.27
Species 7



185.28
Species 8



185.29
Species 9

6. ACKNOWLEDGEMENTS

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