# Early Life History Characteristics of the Razor Clam (*Ensis directus*) and the Moonsnails (*Euspira spp.*) with Applications to Fisheries and Aquaculture

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# EARLY LIFE HISTORY CHARACTERISTICS OF THE RAZOR CLAM (*ENSIS DIRECTUS*) AND THE MOONSNAILS (*EUSPIRA* SPP.) WITH APPLICATIONS TO FISHERIES AND AQUACULTURE

by

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## ABSTRACT

Kenchington, E., R. Duggan and T. Riddell. 1998. Early life history characteristics of the razor clam (*Ensis directus*) and the moonsnails (*Euspira* spp.) with applications to fisheries and aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2223: vii + 32 p.

The razor clam, *Ensis directus,* also known as the Atlantic Jackknife, is found throughout the Maritime provinces. It is most common on intertidal sand and mud flats and is often found among populations of other bivalves such as soft-shell clams, bay quahogs and bar clams. Razor clams are difficult to harvest because of their ability to quickly retract into deep burrows. For the most part, harvesting of this species is restricted to the use of hand held digging tools. The difficulty involved in harvesting razor clams has prevented a large commercial fishery from developing. A small fishery operates on the north shore of the St. Lawrence River in Quebec where subtidal populations are mechanically harvested. The recent discovery of subtidal beds in the Maritime Provinces has prompted attempts to collect them with mechanically assisted harvesting equipment such as SCUBA and hydraulic harvesters. These animals are easily induced to spawn, are fast growing and could be candidates for aquaculture. This report documents periodic collection of razor clams from an intertidal bed on a Nova Scotia section of Northumberland Strait to determine juvenile growth rates, an attempt to monitor growth of razor clams suspended from longlines on a commercial shellfish lease, and attempts at harvesting subtidal beds using scuba and a hydraulic harvester.

The moonsnail, *Euspira heros*, is recognized as a choice bait product for longline gear and presently there is a license to harvest moonsnails for this purpose in Nova Scotia. As bait, moonsnails have been known to sell for $30 a bucket in Yarmouth, N.S. Catch rates can be very high with log records of 449 lb of 1.25-3.5 inch snails trapped in 24 hours. In 1998, moonsnails will be harvested along with the whelk, *Buccinum undatum*, under an exploratory fishery protocol. The animals are tasty and were a staple of the local Acadian diet in the last century. Moonsnails are often referred to as "sweet meats" by local consumers. Also, the large meat of the foot provides a high meat weight to shell weight ratio that is a desirable trait with consumers. Should interest develop in this fishery it would be practical to collect egg collars and introduce them to suitable habitat for enhancement or ranching, or to bring them to hatcheries for culture. Hundreds of egg cases have been collected from the shore on one tide (Wheatley 1947). The production of collars in the absence of sand as documented in this report, and the emergence of healthy larvae from these same collars offers a unique opportunity to monitor the health of the developing larvae while in culture. As many parasites, including nematodes, inhabit the collars constructed of sand, sandless collars may reduce disease outbreak in captivity. While the life cycle of the moonsnail was not completed during this study, the similarity of its development to other culture species such as the oyster and scallop, suggests that this would be a feasible task.

## RÉSUMÉ

Kenchington, E., R. Duggan and T. Riddell. 1998. Early life history characteristics of the razor clam (*Ensis directus*) and the moonsnails (*Euspira* spp.) with applications to fisheries and aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2223: vii + 32 p.

Le couteau, ou couteau de l'Atlantique, *Ensis directus,* est présent dans toutes les provinces Maritimes. On le trouve surtout dans les platins de sable et les vasières de la zone intertidale, souvent parmi des populations d'autres mollusques bivalves, comme la mye, la palourde américaine et la mactre d'Amérique. La récolte du couteau est difficile car ce dernier est capable de s'enfoncer rapidement dans des trous profonds. La majeure partie de la récolte s'effectue à la main, au moyen d'outils de creusage. Les difficultés posées par la capture du couteau ont empêché le développement d'une pêche commerciale à grande échelle. Une petite pêche est pratiquée sur la côte nord du Saint-Laurent, au Québec, où les populations de la zone subtidale sont récoltées à la main. La découverte récente de gisements dans les zones subtidales des Maritimes a été à l'origine de tentatives de récolte assistée par des moyens mécaniques, comme les scaphandres autonomes et les engins hydrauliques. Le couteau se reproduit facilement, croît rapidement et pourrait se prêter à l'aquaculture. Le présent rapport rend compte de la collecte périodique de couteaux d'un gisement de la zone intertidale dans la partie néo-écossaise du détroit de Northumberland, collecte qui vise à déterminer les taux de croissance des juvéniles, d'une tentative d'étude de la croissance de couteaux suspendus à des filières dans une concession de conchyliculture commerciale et d'expériences de récolte au moyen d'un scaphandre autonome et d'un engin hydraulique dans les gisements de la zone subtidale.

La natice, *Euspira heros*, est un appât de prédilection pour la pêche à la palangre. C'est à cette fin qu'un titulaire de permis la récolte actuellement en Nouvelle-Écosse, où son prix a atteint jusqu'à 30 $ le seau à Yarmouth. Les taux de prises peuvent être très élevés et on a enregistré des prises de 449 lb de natices de 1,25-3,5 pouces en 24 heures. En 1998, les natices seront récoltées en même temps que le buccin, *Buccinum undatum*, dans le cadre d'une pêche exploratoire. La natice est un animal goûté qui occupait une bonne place dans l'alimentation des Acadiens de la région au siècle dernier. La partie charnue de son pied est d'un bon rapport pondéral chair-coquille, ce qui est apprécié des consommateurs. Si la pêche de ce mollusque suscite un intérêt, on pourrait recueillir des colliers d'oeufs et les implanter dans des habitats propices à leur développement ou les placer dans des écloseries. Des centaines de sacs ovigères ont été recueillis sur le littoral en une marée (Wheatley 1947). Tel qu'indiqué ici, la production de colliers d'oeufs sans sable, générant des larves saines, offre une occasion unique de surveiller la santé et le développement des larves en culture. Comme de nombreux parasites, y compris les nématodes, infestent les ceintures de sable des masses d'oeufs, la formation de colliers d'oeufs dépourvus de sable pourrait réduire l'apparition de maladies en captivité. Bien que l'étude effectuée n'ait pas porté sur la totalité du cycle vital de la natice, la similitude

entre le développement de cette dernière et celui d'autres espèces cultivées, comme l'huître et le pétoncle, permet de croire à la faisabilité de l'élevage de la natice.

# INTRODUCTION

The concept of aquaculture as an alternative to capture fisheries for the raising and marketing of commercial fishery products is becoming more readily accepted. In order to be able to successfully culture a species, there must first be research to further the understanding of the species' physiology, behavior, nutrition, and general life history. The adaptability of a species to culture conditions, as well as the cost of feeding and maintenance must also be taken into account. These aquaculture feasibility studies are necessary so that a suitable living environment for a particular species can be created.

The first question that must be asked is whether a particular species could be marketed, either for human consumption or use, as bait, or as food for other commercial species. Secondly, the reproductive behavior and early life history of a species must be studied. Whether a species will breed in artificial conditions, how fecund the species is, and how long the early developmental stages last are important questions that must be answered in assessing aquaculture potential (Day 1989).

The duration of the early larval stages is extremely important, as it is during these early developmental stages that there is an increased likelihood of parasitic infection and an increased susceptibility to the effects of handling and other stresses. In general, the following attributes describe most of the species which are currently being cultured successfully (Iverson and Hale 1992):

- the species has a strong market demand, a favorable selling price, and is well known to the consumer (*e.g.*, mussels, clams, scallops *etc.*)
- the biology of the species is well known and there is a considerable body of literature on all of its aspects
- the species lends itself to confinement and handling without harm
- reproduction has been carried out in captivity (*i.e.*, there is control over reproduction, the life cycle is closed)
- the larval life is short
- growth is rapid and survival to market size is high
- the species feeds low on the food chain and/or has a very favorable conversion ratio of feed to fish flesh
- few parasites or diseases are known to cause mass mortality in the culture of the species; for those that do exist there are known methods of prevention and control
- cannibalism, and intraspecific competition do not seriously affect mass rearing of the species
- the species are adapted or are adaptable to local environmental conditions

Since many successful aquaculture species have these attributes, it is predicted that potential aquaculture candidate species with similar characteristics would also be

successful in culture conditions. The purpose of this report is to provide new information on three species which show promise for culture, based upon the above attributes. These are the razor clam *Ensis directus* and the moonsnails *Euspira heros* and *E. triseriata*. As these three species are also considered as developing species in the wild harvest sector, the information on their biology provided within is also relevant to the management of these exploratory fisheries.

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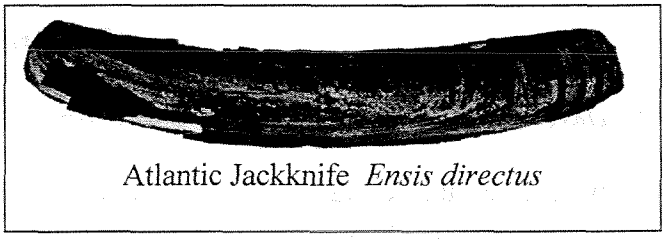
# PART I: RAZOR CLAMS

R. DUGGAN and E. KENCHINGTON

The Atlantic Jackknife, *Ensis directus*, is found along the Western Atlantic Ocean from Labrador to South Carolina (Bousefield 1960). It is also known as a "razor clam" along with other members of the bivalve Family Solenidae. It is one of three razor clams in Atlantic Canada (Abbott and Morris 1995). *Siliqua costata* and *S. squama* co-occur with *E. directus* but are much smaller, rarely exceeding 7.5 cm. *Ensis* has a thin, elongated, slightly curved shell and grows to lengths exceeding 20 cm. Juveniles are first observed in the beds at about 5 cm (Lambert 1994). Colonies of *Ensis* may be found intertidally, and are often associated with other bivalves such as soft-shell and surf clams. Several subtidal beds, 5-8 meters deep, have been located in Eastern Canada. The preferred habitat appears to be gently sloping beaches with shifting sand, but *Ensis* is also found in mud and gravel.



Atlantic Jackknife *Ensis directus*

A large muscular foot, used in combination with jets of water, enables the animal to quickly burrow into the substrate. The foot is also used to propel the animal across the substrate by first extending it in a 'U' shape alongside the shell, then by rapidly straightening the foot; the clam moves forward, siphon end first. Clams may be seen with siphons exposed above the sand but when disturbed will burrow to depths of 25 cm in a few seconds.

Sexes are separate and spawning occurs around early June; eggs and sperm are released through excurrent siphons and fertilization occurs externally. Subsequent development is typical of bivalves and larval stages are similar to other species (Sullivan 1948).

A small commercial fishery (approximately 25 mt per year), which uses hydraulic soft-shell clam harvesters on subtidal *Ensis* beds, operates in the Mingan area of Quebec on the north shore of the St. Lawrence River (*cf.* Lambert 1994). The catch is shucked, frozen, and shipped to Japan. There is apparently a market for live product in Japan and Europe, but animals don't survive well out of water and have a relatively short shelf life. Motnikar and Hotton (1995) report a 10% mortality after 8 days with clams shipped dry in packages of a dozen held with elastic bands, in cold storage. However, after 6 days the clams did not respond quickly to stimulus and the tissues were somewhat dry with a mild odour. Clams sold as a live product should reach the market within 4 days of capture. *Ensis*, when fresh, has a very pleasant mild flavor which is quite distinctive.

Although the Atlantic Jackknife is found throughout the Maritime Provinces there has been no recent commercial fishery for this species. There was a short-lived fishery in

St. Mary's Bay, N.S. from 1951 to 1954 to supplement a depressed soft-shell clam fishery in that area. *Ensis* are now only occasionally harvested for local consumption by people living in the areas where intertidal beds occur. The main deterrent to harvesting is the animals' ability to quickly retract into deep burrows making them difficult to dig out from the sediment. In the United Kingdom, specialized fishers spear the clams for the fresh market, however, this technique takes some skill and has not been widely used in Atlantic Canada. Mechanically assisted diggers are generally prohibited inshore in the former Scotia-Fundy management region (Atlantic Coast of N.B. and N.S.), but are allowed in the former Gulf region. However, some mechanical harvesting of soft-shell clams occurs in Scotia-Fundy as applicants are considered on a case by case basis. There has been some interest in harvesting *Ensis* by this method, however, presently there are no applications being processed.

Studies on the biology and population dynamics of *Ensis* are minimal (Sullivan 1948, Medcof 1958, Lambert 1994, Motnikar and Hotton 1995) but include some density information, a description of the early developmental stages to 1.7 mm, and some aging estimates. The latter suggest a very fast growth rate for this species which would make it a candidate species for aquaculture or ranching operations. While *Ensis directus* has been spawned in the lab (Sullivan 1948), and juveniles have been observed in the field at about 50 mm (Lambert 1994) the time between these events has not previously been determined, and therefore the estimates of age have not been validated. Lambert (1994) estimates that a 14 cm clam is approximately 5 years old. This age was derived from the prominent growth rings on the shells. This report documents periodic collection of razor clams (*Ensis directus*) from an intertidal bed on a Nova Scotia section of Northumberland Strait for the purpose of determining growth rates and population size structure. This information was collected in order to evaluate the potential of this species for aquaculture and for suggesting size limits for commercial harvesting in the Maritime Region.

## MATERIALS AND METHODS

### STUDY SITE

Boss Point, N.S., was chosen as a sampling site and sample times were arranged to correspond with lowest tides during daylight hours (Fig. 1). The site is a high energy area with extensive sand bars that has traditionally been utilized to harvest large bar clams (*Spisula solidissima*). The inner area has a harvesting restriction for all species in an established Environmental Protection Service closure zone due to presence of coliform bacteria (Fig 1). This area is effectively a refugium for broodstock and is more heavily populated with razor clams than bar clams. The sampling site was about 50 m outside the closure line.

## FIELD PROCEDURES

The shell length frequencies from the *Ensis* population over time were determined. Field collections were made on 9 occasions from May, 1995 to November, 1996 during the spring, summer and autumn months: May 29, 1995; June 15, 1995; June 29, 1995, September 8, 1995, October 12, 1995; April 18, 1996; May 16, 1996; July 2, 1996, November 15, 1996.

Distribution of clams at Boss Point was patchy at the sampling location. All sizes of clams were found throughout the site and there didn't appear to be concentrations of similar sizes. Counting clam holes after haphazard tossing of a 1/4 m square quadrat yielded densities of 0 - 24 clams per square meter. Deliberate placing of the quadrat gave maximum densities of 24 clams per square meter. Some difficulty was experienced in obtaining consistency of samples on collection days; rain on the sandbars would obscure clam holes making it almost impossible to collect any animals let alone a variety of sizes, and onshore winds and variances in tide heights affected the time the sample site was exposed for collection. This experience was similar to that of Bourne (1969) who was unable to obtain accurate density measurements of the Pacific coast razor clam (*Siliqua patula*) by the methods of counting holes or "shows", repeated digging and tagging census. Therefore no attempt was made to estimate the size or biomass of the population. Random quadrats were sampled to determine only the length distribution of the population. Samples were obtained by digging with a round pointed shovel within the quadrat. Clams were washed and transported to the laboratory where they were measured to the nearest 1 mm with vernier calipers. Data were recorded on computer and length frequency histograms were plotted.

## HANDLING OF LIVE CLAMS

Several methods were tested to try to determine the most efficient way to transport samples. Clams were wrapped in damp newspaper or paper towel and packed with freezer packs in coolers, some were allowed to burrow in coolers filled with damp sand and others were bundled in groups of 10-12, wrapped with elastic bands and transported in coolers with ice or freezer packs. Time from collection to measurement was usually during the same day and on two occasions extended overnight but less than 24 hours.

## SPAWNING PROCEDURES

Samples collected from Boss Point on the Northumberland Strait coast of Nova Scotia on May 16, 1996 were transported and kept overnight at 4-5 $^{\circ}$C in a cooler. The following morning, on May 17, they were transferred to the lab where they were placed in running seawater at 15 $^{\circ}$C. During measurement of shell length, it appeared that one animal had started to spawn. Immediately a number of animals were selected, placed in trays of sterilized seawater at ~20 $^{\circ}$C and observed for evidence of spawning. Within 15-

20 minutes several animals appeared to be spawning. A strong excurrent was readily discernible from a number of individuals and after a short period of observation, males and females could be distinguished. Reproductive material from both sexes appeared at first to be white. The sperm quickly became a milky cloud, obscuring vision to the bottom of the bucket, while the eggs were more granular and, when concentrated, had a slightly yellow tinge. Sampled eggs were ~ 70 μm in diameter. Animals collected from a subtidal bed on the Atlantic coast at Prospect, Nova Scotia were also spawning at this time.

Males and females were then placed in individual containers and allowed to spawn for about 35 minutes. Sperm from several males was pooled in a separate container. Eggs were fertilized by transferring 50 mls of sperm to the female containers and physically stirring the contents. A sample was also taken from containers where both males and females had started to spawn before being separated. This was kept out of curiosity and was not expected to produce viable larvae because of polyspermy.

Microscopic observation confirmed fertilization in both cases and eggs, at a concentration of ~200/ml, were transferred to clean five litre plastic buckets. Development progressed through to the trochophore stage which was photographed about 24 hours later. The larvae were fed with lab cultured Tahitian *Isochrysis*. The buckets were maintained at 18°C in a temperature controlled room. The larvae were screened daily and transferred to buckets with clean water and fresh food. Screen sizes were increased gradually from 40 to 60 and finally to 110 μm after ten days. *Skeletonema costatum* was added to the food supply after May 28.

Larvae were transferred to a bucket with a sand substrate from the collection area to see if they would begin to burrow. The larvae settled and burrowed into the sand. Cultured phytoplankton was added to the containers several times a week and juveniles reached lengths of 7-9 mm by August 7, 1996.

## RESULTS

### SPAWNING AND LARVAL REARING

Larvae were mobile and appeared to be healthy. Sizes averaged 106 x 136 μm by May 22, 1996 when the larvae were 5 days old. The larger, *i.e.*, ~150 μm length, were beyond the straight hinge stage at this point. Average size increased to 174 x 204 μm by May 28 (11 days old) at which time the larvae from the uncontrolled spawning averaged 186 x 215 μm.

The larvae progressed through the pediveliger stage after 15-16 days and a large foot about half the width of the shell (still typical clam shape) could be seen. The foot had an appendage which looked like the thumb of a mitten (the foot looking like the hand

of a mitten, although somewhat elongated) protruding from one side. Larvae were using the foot to propel themselves across the slides much like juveniles do to move across the sediment. Average size was 245 x 206 μm.

Larvae were transferred to a bucket with Northumberland Strait sand, from Boss Point, and burrowed into the sand. Juveniles reached lengths of 7-9 mm by August 7, 1996 (approximately 3 months post spawn). Transition from typical clam shape to elongated shell at about 1.7 mm was not observed (Sullivan 1948), apparently this occurs after initial burrowing.

## SHELL LENGTH DISTRIBUTION

The sample collected in May 1995 from Boss Point, N.S. appeared to have three distinct modes in the length frequency histogram (Fig. 2). Small animals, < 20 mm, were absent from the samples until September, 1995. Concern that this observation may have been the result of experience gained in locating small holes in the sand was removed when the same pattern was observed in 1996 (Fig. 2). It would appear that the animals detected in the first mode on May 29, 1995, at 33 mm shell length, were one year old animals spawned in May of 1994. The 1995 year class first appears in September, 1995 (Fig. 2, 3). At this time the animals are on average 18 mm in length (Fig. 3). The 1996 year class first appears in the November 15, 1996 sample (Fig. 2).

The average size of the first mode (Fig. 2) is tracked in figure 3 by recording the average shell length plus standard error for all animals under 60 mm shell length and corresponding to the first data mode, in each sample. Animals grew approximately 33 mm in their first year. Growth was slowest during the winter when only 4 mm were put on the shell between October 12, 1995 and April 18, 1996. It is during this period when the ring visible on the shell is formed.

In addition to the above results, observations on culture and harvesting of razor clams were made through collaborative projects with industry. These observations are reported below:

## TRANSPLANTATION OF RAZOR CLAMS

A number of razor clams were collected to compare natural growth rates with those of specimens kept continuously immersed by suspending them in trays hung from longlines on two commercial shellfish leases. These animals were placed in individual containers in the trays and periodically measured. The clams on the leases had poor survival rates and despite efforts to keep them confined with net covers some escaped and several were found dead after wedging themselves in the netting.

## HARVESTING STRATEGIES

In collaboration with industry several attempts were made to try to harvest razor clams from subtidal beds. One attempt involved the use of SCUBA where divers used compressed air from scuba tanks to try to either displace the animal from its burrow or use the pressure to remove the sediment. A second trial utilized a hydraulic dredge normally used to harvest ocean quahogs.

These harvesting strategies were largely unsuccessful. Compressed air was used to harvest clams on a bed on the Atlantic coast of Nova Scotia, near Prospect. SCUBA divers directed air pressure through a piece of stainless steel tubing (inside diameter 5 mm) held onto the clam holes. Air pressure was delivered on demand through a spring loaded trigger valve but was not effective in displacing animals from their burrows.

A hydraulic dredge, normally efficient for harvesting bivalves, was tested in an upper area of St. Mary's Bay in the Bay of Fundy where razor clams had been reported. A small number of clams was collected but they were under market size and didn't appear to be in very good condition. It was decided that there were not sufficient clams in the area to consider further attempts at a commercial harvest.

# DISCUSSION

This study has elucidated the early life history and growth of *Ensis directus* in the Maritime Region. The spawning time is in the spring with animals fertile in mid-May. Animals spawned at this time in the laboratory reached a shell length of 7-9 mm by early August. In the field, spring-spawned animals were first detected in early September when the average shell size is 18 mm (range 11-24 mm). Growth continues through the fall but slows from October to April. One year old animals visible the following spring form a distinctive shell height mode at about 33 mm. Lambert (1994) reports that in the North Sea *Ensis* reaches a shell length of 80 mm after 2 years and 150 mm after 5 years. In this study, growth is slightly faster with animals reaching 80 mm in approximately 1.5 years. With such a rapid growth rate a minimum size should be imposed on developing fisheries to ensure that the animals are not harvested before they have had the chance to spawn at least twice. A shell length of 100 mm would permit animals to spawn twice, however the fecundity of the animals in their first year is probably not high. A minimum shell length of 120 mm would be more conservative.

There is a widely distributed resource of razor clams in the Maritime Provinces, however the probability of a commercial harvest of this species seems unlikely in the near future given the difficulties involved with harvest and transport. The rapid growth of this animal may offer potential as a species for aquaculture if subsequent research can develop suitable growout techniques.

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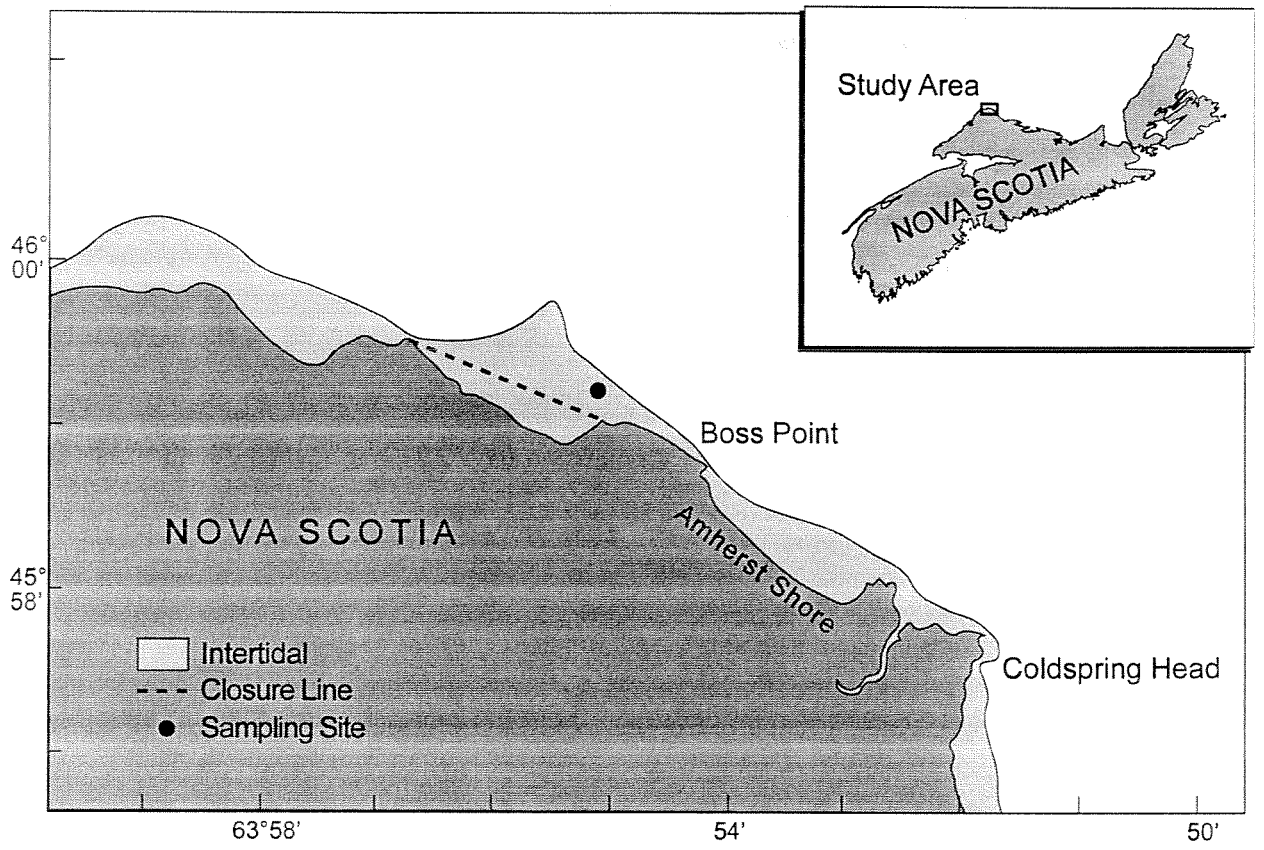


Figure 1. Location of sampling site at Boss Point, Nova Scotia for collection of *Ensis directus* shell length frequency data. The intertidal area is marked as well as the line demarcating the area closed because of bacterial contamination.

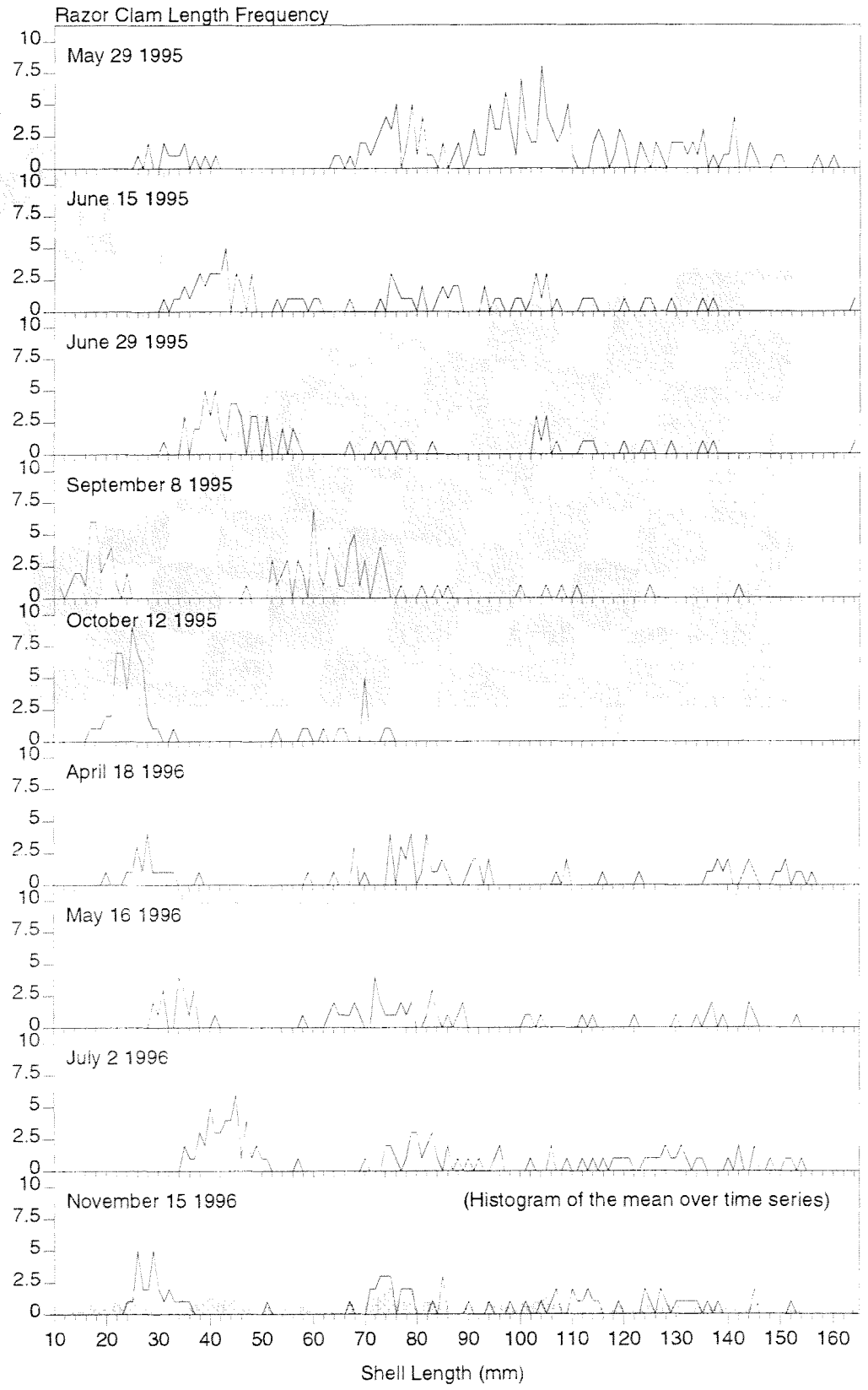


Figure 2. *Ensis directus*. Shell length frequency distribution of clams sampled at Boss Point, Nova Scotia over a two year period.

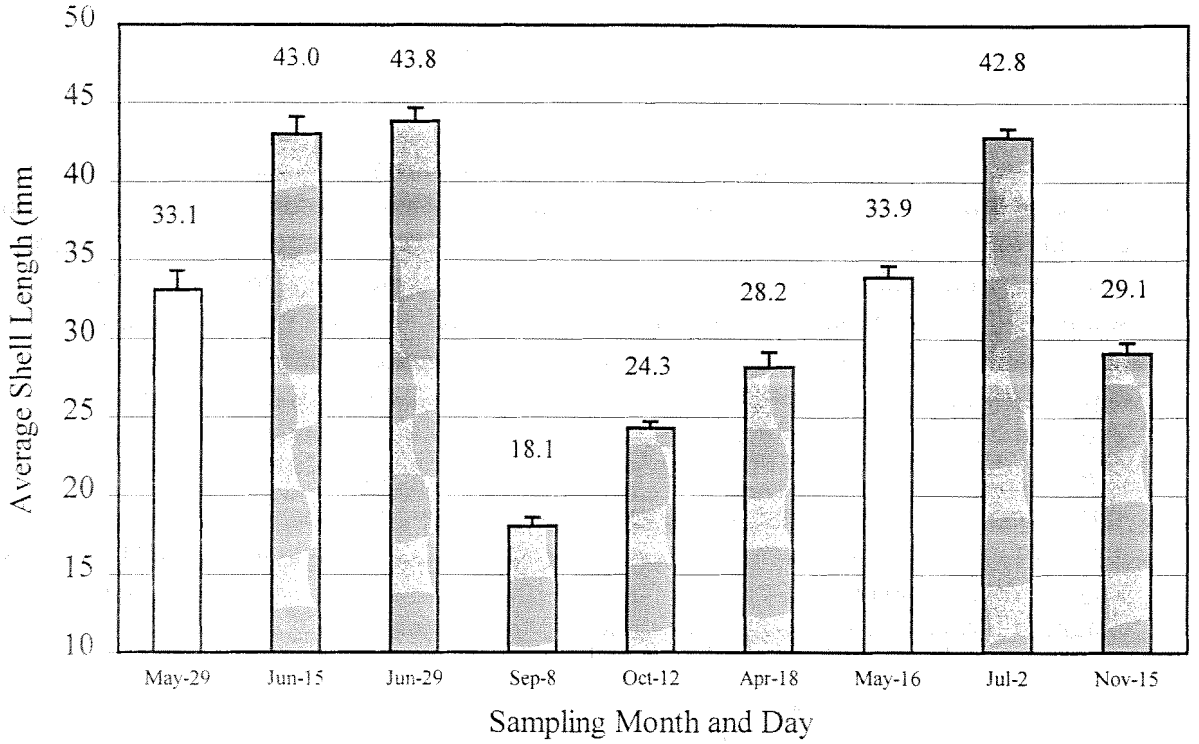


Figure 3. *Ensis directus*. Mean shell length (plus standard error) of *Ensis directus* less than 60 mm shell length (see Fig. 2) sampled at Boss Point, N.S. from May 29, 1995 to November 15, 1996. The open bars identify the May samples from 1995 and 1996 to illustrate the growth of the 1994 and 1995 year classes (1996 year class first observed in November 15, 1996 sample).

# PART II: MOONSNAILS

T. RIDDELL and E. KENCHINGTON

The moonsnail (Genus: *Euspira*; syn. *Polinices, Lunatia*; nomenclature following Turgeon *et al.* 1988) is a member of the Naticid family and is found commonly in most coastal areas in the Atlantic region (Giglioli 1952). Moonsnails are distributed throughout the Gulf of St. Lawrence and around Nova Scotia to the Bay of Fundy and south to North Carolina. They are particularly abundant in some areas. The moonsnail is found on bottoms of mud, sand, or a mixture of sand and gravel, from low water line to a depth of 40 fathoms. However, they are more common in shallower water to 17 fathoms. They are capable of burying themselves to a depth of approximately 6 inches (15 cm). Moonsnails are rarely found in rocky areas. The moonsnail is a nocturnal predator which buries under the sand during the day and emerges in the evening to feed, and to mate in the reproductive season. These animals are able to sense proteins in the water from their prey. Many predatory marine gastropods (most commonly *Buccinum undatum*) are caught in lobster traps, having entered the trap to consume bait.

The moonsnail uses a radula and boring gland to drill a hole in the shell of its prey. It first scrapes the calcium carbonate shell of the prey animal. The snail then applies its salivary gland that releases an acid to further dissolve the shell. Drilling is slow and can take several hours to complete (Hyman 1967). When the hole is finished, the moonsnail inserts it's proboscis and digests the soft tissues of the animal. There is a high correlation between the diameter of the drill hole and the shell diameter of the moonsnail predator (Vencile 1997). The snail is known to feed on a number of species, most commonly on soft-shelled clam (*Mya arenaria*) and on the blue mussel (*Mytilus edulis*) (Wheatley 1947, Giglioli 1949, Vencile 1997). This mode of feeding has led to the common name of "drill" being used in areas where the moonsnails are destructive to bivalve fisheries. Naticid predation on bivalves and gastropods has been traced back to the Precambrian period, 550 million years ago (Bengtson and Zhao 1992). The oyster drill is a separate species, *Urosalpinx cinerea*.

Early documentation on the moonsnail in the Maritimes was carried out at Belliveau Cove, Nova Scotia and at the St. Andrew's Biological Station in New Brunswick. Studies were conducted primarily to find information on reproductive and feeding behavior of the drill, to determine the extent of the damage being caused to the soft-shell clam industry (*Mya arenaria*) in the Maritime region (Stinson and Medcof 1946, Larocque 1948, Thurber 1949). It was discovered that the destructive capacity of *Euspira* was considerable and that a single drill would consume as much as 0.3-0.8 bivalves per day (Wheatley 1947).

Most work was conducted on two species of moonsnail, *Euspira heros* and *E. triseriata*, although there are five other closely related species known to be found in Atlantic Canadian waters. Studies were designed to assess the best way of controlling

these predatory species based on their early life histories, and reproductive and feeding rates. It was decided that the best way to control these species was to gather the egg cases of the animals which could be found in large numbers on the intertidal flats (Wheatley 1947). The egg cases are easily distinguishable from the egg masses of other whelks on the intertidal flat as *Euspira* egg cases are distinct egg collars (Fig. 4), like "bowls with the bottom knocked out" (Melville 1930).

The egg cases contain egg capsules; gelatinous filled spaces containing the eggs. Larvae of *Euspira* are released as planktonic veliger larvae, which is a common larval form in many marine molluscs. The egg capsules contain between one and thirty eggs, and the number of eggs within each capsule can be used as a diagnostic character of different species. Most previous studies conducted on the egg case were based on *in situ* observations, and little information was gathered as to the success of these species in artificial conditions.

*Euspira heros* is the larger of the two species found most commonly in the Atlantic regions (Fig. 5). In this species the ratio of height: width is approximately 1 from larval stages to adult (Giglioli 1949). The shell is gray or white with a deep umbilicus. The foot is large and appears black when retracted, and the shell aperture is covered by a corneous, gold operculum. It has a maximum height of 80 mm (from the dorsal lip of the aperture to the back of the final whorl) and females are larger than the males at maturity (Giglioli 1949).

The egg collars of *E. heros* have a wide distribution from the Gulf of St. Lawrence to North Carolina. The cases are large with a height averaging 25-73 mm and a length of 202-512 mm (Fig. 4). The walls of the egg case are thin (1 mm or less) and flexible, and individual egg capsules cannot be seen or felt on the surface of the collar. Egg cases of this species are generally found in deeper waters and have been found as deep as 238 fathoms (Melville 1930). No information could be found on the exact laying period of this species although papers do report observations on this egg case from early May to late August (Wheatley 1947, Larocque 1948, Beairsto *et al.* 1965).

This species is very fecund and each egg case laid contains approximately 127 egg capsules per square centimetre, with an average of 27 eggs per capsule (Giglioli 1955). Previous literature on the length of intracapsular development is variable and has been estimated at anywhere from eight days to six weeks (Stinson and Medcof 1946, Wheatley 1947, Giglioli 1949, Beairsto *et al.* 1965). At the time of hatching, the egg case crumbles and planktonic veliger larvae are released into the water column. The larvae have ciliated velar lobes, two eyespots, and a transparent uncoiled shell. Beairsto *et al.* (1965) did note that *E. heros* laid egg cases in a captive situation, but failed to mention the conditions under which successful laying was achieved. It was also not clear whether the egg cases laid reached the hatching stage producing healthy emergent larvae.

*Euspira triseriata* is smaller, never having been found exceeding 30 mm in height (Giglioli 1949). The shell is gray or white in adult snails, but is light pink or blue in

juveniles of the species, with three distinct chestnut bands or spots. The foot is white or yellow in colour even when retracted, which is one method for differentiating between the two species, as adult *E. triseriata* and juvenile *E. heros* look remarkably similar. The egg collars of *E. triseriata* have the same range as that of *E. heros* and laying begins in June, peaks in July and continues on until late August or early September (Wheatley 1947). Egg collars are small relative to *E. heros* with an average width of 10-25 mm, length of 42-85 mm and a thickness of about 1 mm (Giglioli 1955). The walls of the collars are inflexible, and slightly more dense than those of *E. heros* due to the larger size of the sand grain used in the construction of the case. Capsules are large (850-1150 μm) with usually one, but up to three eggs per capsule. The emergent larvae are approximately 1000 μm long with a red-brown shell and one and a half whorls, as described by Stinson and Medcof (1946) and Wheatley (1947). There has been some debate as to whether the snails emerge as benthic or semi-planktonic larvae. The larval state seems to depend on the length of intracapsular development (5-7 weeks) and the time at which the collar was laid (Giglioli 1955).

While these two species are the most common, there is a third species of interest which is known only as "Unidentified Canadian Species", as it is only known through it's egg cases, *i.e.*, the parent snails have never been identified to the case and may never have been recorded or described at all. This species is of interest as the larvae undergo all of the early developmental stages within the egg case and emerge as a large post-veliger juvenile. This aspect of the life history is a considerable advantage to aquaculture as larval husbandry can be avoided entirely. The egg cases have been collected from Digby to the Gulf of St. Lawrence and are generally found in deep waters (14-45 fathoms). The egg case has been described in detail by Giglioli (1955). The egg collars are 35-57 mm wide, 172-315 mm long and 2.5-3.4 mm thick. The walls are inflexible and the egg capsules (1910-3202 μm) are clearly visible on the exterior surface of the collar (Giglioli 1955).

This study extends these earlier investigations to include observations and experimentation on the reproductive life cycle of *Euspira heros*, *E. triseriata* and the Unknown Canadian Species. Specifically, data were collected on food preference, mating behavior, egg laying and settling behavior of *E. heros*, intracapsular development under different temperature regimes in *E. triseriata*, post-metamorphosis growth and tentative identification of the Unknown Canadian Species, and observations of cannibalism.

# MATERIALS AND METHODS

## LARVAL EXPERIMENTS

### *Euspira heros*

The initial experiments to hatch moonsnail egg cases were conducted with *E. heros*. Both adult snails and egg cases of this species were collected in a scallop drag in the Annapolis Basin off the coast of Digby, Nova Scotia in late June, 1994. Adult snails were maintained in 3 ' x 3 ' flow-through salt water tanks, and were provided with several bivalve prey species as food (*Mytilus*, *Venericardia*, *Mya* and *Placopecten*). The water was kept at ambient sea temperatures from June until mid-August, at which time they were transferred to a new tank which was kept constant at 15 °C.

Three egg cases were each placed into separate 4 L buckets. The buckets were filled to 3 L with 2 μm filtered sea water. The buckets were then placed in a 12 °C water bath. The water in the buckets was changed every two days and replaced with fresh filtered sea water. After hatching, descriptions of the emergent larvae were recorded. The remains of the egg cases were removed. The larvae were washed using a 100 μm screen with filtered sea water every other day and placed back into the bucket.

### *Induction of Metamorphosis*

In order to try to induce metamorphosis in the emergent veliger larvae, a number of different experiments was conducted. The first egg case to hatch released many thousands of swimming larvae. These larvae were divided into five approximately equal groups by stirring them in the bucket and pouring them out in equal amounts. Each group was placed into a separate 4 L bucket and filled to 3 L with filtered sea water.

To the first bucket was added mussel spat (*Mytilus*) that were approximately 1 mm or less in length. A few drops of homogenized herring was added to the second bucket, and a small intact piece of herring was added to the third. To the fourth bucket was added 40 ml of unicellular algae (*Isochrysis*, *Chaetoceros*, *Thalassiosira*, *Skeletonema*) at different times. All other larvae were kept in filtered sea water with nothing added. The water in the buckets was changed every second day and the larvae were rinsed through the 100 μm screen. All buckets were kept in the 12 °C bath.

The second experiment to induce metamorphosis involved varying the substrate particle size. Approximately equal amounts of larvae were added to 4 L buckets containing either fine-grained sand from the Annapolis Basin (particles 1 mm or less), or standard aquarium gravel (average particle size 1 mm or greater). In another two 4 L buckets approximately equal numbers of larvae were added to 3 L of 2 μm filtered water. One bucket contained fine-grained Annapolis Basin sand and one the aquarium gravel.

Both contained a small piece of algae (*Fucus vesiculosus*). The water in all the buckets was changed every other day, and kept in the 12 °C bath.

The final experiment to induce metamorphosis involved the addition of an adult snail to a bucket containing only filtered seawater. The adult was allowed to move across the bottom of the bucket and leave a mucous trail from it's pedal sole. The adult snail was then removed from the bucket. Several hundred larvae were then added to the bucket and left in the 12 °C water bath. The water was changed every second day and the larvae were washed on a 110 µm screen. The adult left a new mucous trail each time before the larvae were re-added to the bucket after each water change.

Due to the large number of larvae hatched at this time, it was not possible to quantify survival and mortality. Instead, observations on the general appearance of the larvae (*e.g.*, healthy, unhealthy, parasitized, *etc.*) and the relative amounts of surviving *vs.* dead larvae were recorded.

*Eusprira triseriata*

Egg cases and adult snails of *Euspira triseriata* were collected from the intertidal flat at Digby in early August, 1994. The adult snails were added to the flow-through tank already holding the adult *E. heros* and were kept at ambient sea temperatures until mid-August. Since the egg cases of this species are found on the intertidal flat, they are submerged much of the time in shallow, warm water. It was predicted that the larvae would develop more readily in warmer water temperatures (above 15 °C), so the egg cases were added to separate 4 L buckets filled with 2 µm filtered, UV treated sea water at 18 °C. The water in the buckets was changed every three days until the larvae hatched. Observations on the appearance of the larvae, and the average length (measured to the nearest 0.00 mm with an ocular micrometer) at the time of hatching, were recorded.

*Effects of Temperature on Intracapsular Larval Development*

Three egg cases were kept separately for an experiment to determine the effects of temperature on the growth of the larvae during their intracapsular development. Since the exact laying time of all the egg cases was unknown, the three egg cases could not be matched for age. Instead, these egg cases were labeled A, B and C and each was divided into three equal pieces. Each of the three pieces of egg case A was placed into a separate 2 L bucket in filtered sea water. Each of the three buckets was then held at one of three temperatures (4, 15, 18 °C). The same procedure was followed for egg cases B and C. Initial measurements were taken for each piece of egg case at each of the three temperatures. To do this, a small piece of each egg case was sampled (approximately 2 $mm^2$ or 4-6 egg capsules). The sand from one side of the egg case was scraped away exposing the egg capsules. Removal of the top of the capsule with a sharp scalpel allowed the larva within to be removed and it's length measured. Measurements of four

larvae from every piece of each egg case at each of the three temperatures were carried out once a week for four weeks.

A two-way ANOVA was performed on the data collected during the fourth week of the experiment to test for differences in the length of the larvae between the three temperatures within each egg case.

Unknown Canadian Species

A single egg case of this species was brought up with *E. heros* in June, 1994 in the scallop drag at Digby. The egg case was initially kept with the adult snails in the flow-through sea water tanks in ambient sea temperatures until mid-August. The case was then transferred to a 4 L bucket filled with 2 µm filtered, UV treated sea water and maintained at 18 °C. Water within the bucket was changed every four days. The remains of the egg case were removed after hatching to lessen bacterial contamination. The larvae were then transferred to a 250 ml bucket containing some fine-grained Annapolis Basin sediment (average particle size less than 1 mm) and many mussel spat (8 mm in length or less). Several larvae crawled out of the water and died so a mesh screen was placed over the bucket, and the entire container with the screen was submerged in filtered seawater.

Forty ml of seawater containing high concentrations of unicellular algae (see above) were added to the bucket after it was removed from the tank. This was three times a week. done to feed the mussel spat. After the mussels fed the bucket was again placed into the tank. Measurements of larval length had to begin three weeks after larval emergence due to high mortality of the larvae during the first weeks. The larvae were provided with new mussels as they were eaten. Measurements of both larval length and prey length (measured to the nearest hundredth of a millimeter) were carried out once every two weeks for the first five weeks and then once each week for the remaining seven weeks of the experiment. A regression and ANOVA were performed on the larval length data over the twelve week growth period to determine whether growth differed significantly from zero. Further regression analyses were performed on the mean length of mussel spat being consumed by the larvae *vs.* the mean length of the larvae to test the hypothesis that their means were equal.

REPRODUCTION IN CAPTIVITY

A 4 L bucket of fine grained Annapolis Basin sand was added to the flow-through tank containing adult animals in late June 1994. The sand was the same grain size of the sand used by the snails to make egg cases (particle size 1 mm or less) in the wild. Observations were made on the laying behavior of *E. heros* and *E. triseriata* in this tank until mid-August. At this time the two species were separated and each was added to a new 3'x 3' flow-through tank maintained at a constant 15 °C. Both species were provided with mussels and clams to eat on a continuous basis. Fine-grained sand was

provided to both species. Observations were again made on the laying behavior of both species for several months.

## FEEDING EXPERIMENTS

A feeding experiment was conducted on *E. heros* from mid-January to mid-February 1995 to observe the feeding preferences of the adult snails and to determine their feed to flesh ratio. Initial weights and lengths of the eight adult snails were taken when they were completely withdrawn into their shells. Each of the eight snails was then added to separate 4 L buckets containing 1.5 inches of aquarium sand. To each bucket was added a mussel (*Mytilus*), a clam (*Mya*) and a periwinkle (*Littorina*), and a piece of raw fish (cod). The size of the prey items was matched by approximation to the size of the snail to which they were fed. All prey items were weighed before being added to the buckets.

Observations were carried out each day to determine which prey item was fed upon first by the adult snails. After a prey item had been eaten, it was removed and a final weight measurement was taken of the remaining parts (shell, tissue). A new prey item was then added to the bucket. After 23 days, the final weights of the snails were recorded and the total amount of flesh consumed (in grams) was calculated for each snail.

A chi-square goodness-of-fit test was performed to determine whether the adult snails selected prey items at random or if a preferred food item was more often selected first for consumption. Further examination of the data involved performing a multiple regression ANOVA on weight gain *vs.* total amount of flesh consumed (in grams) and initial weight of the individual snails.

# RESULTS

## LARVAL EXPERIMENTS

### *Euspira heros*

Before the egg cases hatched, the trochophore larvae could be seen swimming within the egg case capsules. The larvae did not have a shell at this time. The *E. heros* egg cases began hatching in the third week of June, three weeks after they were brought in from Digby. The larvae emerged as veligers. They were 284 μm in length at the time of hatching with a standard deviation of 47.5 μm. The larval shells were transparent and the internal structures could be seen clearly. The foot was present but not fully developed, with a corneous opercular covering. Two black eyespots were present. The velar lobes were still present and the larvae were swimming after hatching. A gut tube became visible in most larvae that survived after 6-7 days (Fig. 6).

In the three buckets containing the larvae with the mussel spat, homogenized herring and chunked herring, a rapid degeneration of the healthy appearance of the larvae took place. The larvae acquired a brown 'fuzzy' appearance and there was often the presence of nematodes or parasitic microorganisms in the mantle cavity of many of them. All larvae died within 9 days of hatching in these three conditions. The larvae in the bucket which had nothing added underwent the same health degeneration but at a slower pace. The larvae in this condition were all dead within 14 days. The larvae in the bucket to which only unicellular algae were added remained relatively healthy for 17 -19 days after hatching. Rapid degeneration of the healthy appearance of these larvae took place after the third week. All larvae with this treatment were dead within 28 days. Many snail larvae set on the bottom in this treatment condition but the larvae which settled died soon after.

In the buckets which contained the sand and gravel, the death of all the larvae occurred within one week. There was a very rapid decline in the appearance of the larvae. Larvae underwent metamorphosis quickly and in much larger numbers in the buckets containing Annapolis Basin sand than in the buckets containing the aquarium gravel. The presence of algae did not appear to alter these results in any way.

The bucket in which the adult snail left a mucous trail showed rapid mortality of larvae. No metamorphosis occurred within this treatment. There also appeared to be a relatively greater proportion of larvae with parasitic infections and nematode invasions in this condition. All larvae died within one week.

Euspira triseriata

All egg cases of this species that were collected but not used in the temperature experiment hatched and released larvae that were on average 0.89 mm in length with a standard deviation of 0.27 mm. The larvae all possessed a well developed foot and opercular cover. All larvae that emerged were entirely benthic and no larva possessed a velum. The shell was golden-brown with 3/4 of a whorl.

*Effects of Temperature on Intracapsular Larval Development*

The mean length (plus standard error) of intracapsular larvae from each of the egg cases under the three temperature regimes over 4 weeks is illustrated in figure 7. ANOVA showed a significant growth of the larvae in all egg cases. There was a significant interaction between egg case and temperature. In egg cases A and C, there were no significant differences in the length of the larvae at week four in the 15 and 18 $^{o}$C temperatures. There was a significant difference in the length of the larvae in the 15 and 18 $^{o}$C temperatures for egg case B. In all three egg cases, there was a significant difference in the length of the larvae between the two higher temperatures (18 and 15 $^{o}$C) and the 4 $^{o}$C temperature. In all egg cases regardless of length, the larvae began hatching from the egg case first in the 18 $^{o}$C temperature treatment. These data suggest that the larvae experience an accelerated rearing time with increased temperature between 15 and

18 °C, but not an increase in final size at hatch. Egg cases kept at 4 °C failed to produce emergent larvae.

Unknown Canadian Species

A high mortality of larvae was observed within the egg case before emergence occurred (approximately 75% of all larvae within the egg case). Fewer than 25% of the larvae within the egg case lived to hatch. At emergence these larvae were 2.1 mm in length with a standard deviation of 0.17 mm. The larvae that emerged each possessed a white opaque shell with 1.5 whorls. A well developed foot was also present, and there was an absence of any velar structures.

Growth rates between individual larvae varied with a maximum of 0.15 mm per week and a minimum of 0.04 mm per week. The average shell length and standard error for each observation are illustrated in figure 8. Growth is modeled by an exponential equation with a $R^2$ value of 0.98 (Fig. 9). Average rate of growth varied significantly from zero ($t=6.8$, $P = 0.0$).

Emergent larvae began eating mussel spat within three weeks after hatching. The average size of the mussel spat prey is compared with the average size of the moonsnail larvae in figure 9. In a regression of mean mussel spat length *vs.* mean larval length at a given date, the difference between means were found to be insignificant ($t=2.3$, $P > 0.1$). As development of the larvae continued, a change in the appearance of the shell was observed; the shell became abraded, and the outermost whorl became black.

REPRODUCTION IN CAPTIVITY

Within the holding tank mating behaviour by several different snails while they were being held at ambient sea temperatures was observed. The two sexes embraced one another on the surface of the sand and remained coupled during copulation. This behaviour may not be representative of mating in the wild, as the animals were not provided with enough depth of substrate to bury. Adult *E. heros* laid egg cases in the flow-through tanks during the summer months until mid-August. Five cases were laid in the fine-grained Annapolis Basin sand from August 1-15. Attempts to brood these egg cases in buckets at twelve degrees were unsuccessful. Bacterial infection of the egg cases appeared to be the primary reason for their lack of development. It was unknown which of the snails laid three of the egg cases but it was observed that one large female (8.19 cm) laid at least two of them. It was noted that once, during an accidental cooler malfunction when the temperature dropped below 0 °C, the large female began to produce an egg collar when the water warmed again.

After the snails had been moved to a flow-through tank that was maintained at a constant 15 °C, no further mating behavior or laying of egg cases was observed during their regular laying period. Laying by *E. heros* resumed in mid-February. Two whole egg cases and several small pieces of egg case were laid be a smaller female (5.45 cm).

The cases were abnormal in that the snail incorporated both fine grained Annapolis Basin sediment and small amounts of aquarium gravel into the walls of the collar. In one case no sediment at all was incorporated into the walls. When observed under the microscope the trochophore larvae could be seen swimming within the egg capsules. Healthy larvae began to emerge 2-3 weeks after the egg cases had been laid.

*E. triseriata* did not lay any egg cases in the tanks at ambient temperatures. No mating behavior was observed for this species at any time during their containment. Attempts to inducing mating and laying by increasing the temperature were unsuccessful.

FEEDING EXPERIMENTS

Several snails began feeding on the first day of the experiment. A chi-square goodness -of-fit test showed that the adult *E. heros* did not choose their prey items at random, but selected certain foods preferentially. In this experiment, the clams were the first choice, followed closely by mussels and dead fish. Periwinkles were never chosen. Both the amount of food consumed by the snails and the snails' initial weight were found to be insignificant ($F=1.57$, $P>0.1$) in explaining the weight they gained. Since the amount of food that was eaten did not explain the weight gained by the snails the feed:flesh ratio was not calculated. This method of determining food conversion is undoubtedly confounded by changes in the shell weight and water retention irrespective of diet.

In addition to the above experiments it was noted that the moonsnails did not exhibit cannibalism throughout the holding period, however, *E. heros* did prey on *E. triseriata* in the absence of other food items.

## DISCUSSION

Many marine mollusc larvae require complex chemical or physical cues before metamorphosis will occur. In the lab, the attempts to cause settlement in *E. heros* veliger larvae were largely unsuccessful. Failure to induce metamorphosis may have been the result of many variables. There were no specific chemicals added to the water where the larvae were hatched and reared. It is known that many bivalves, echinoderms, coelenterates and gastropods require dissolved chemical inducers (*e.g.*, glycoproteins, certain polar lipids, or L-DOPA) from bacteria found in the adult environment before metamorphosis will take place. Similarly, neuroactive compounds such as epinephrine and norepinephrine alone have induced settling behaviour in the veliger larvae of many invertebrate species (Nell *et al.* 1994). Elevated levels of KCl (20 mM above ambient) have also caused metamorphosis in marine gastropods (Lima and Pechenik 1985, Pechenik and Eyster 1989, Zimmerman and Pechenik 1991). The veliger larvae of *E. heros* may require one of these chemical compounds to be present before metamorphosis will occur in culture.

The Japanese abalone (*Haliotis discus hannai*) has similar larval development (from planktonic veliger to benthic juvenile) to that of *E. heros* and has been successfully cultured for many years. It is known that mucous trails left by the pedal sole of juvenile and adult abalone will trigger metamorphosis in the veliger larvae of this species (Seki and Hisashi 1982). Similar results were not obtained for *E. heros* in this study. Since the mucous from the pedal sole is composed primarily of polysaccharides, this may have contributed to increased bacterial growth and contamination, which resulted in the poor survival of the veligers in these treatments. It is unknown whether bacterial contamination was the main cause of mortality or if it occurred after many larvae had already died. It has been shown that certain types of bacteria are essential to the development of some marine invertebrates (Fitt *et al.* 1989).

Higher numbers of larvae underwent metamorphosis in the bucket containing the Annapolis Basin sediment than the aquarium gravel. This suggests that the settling behaviour of *E. heros* is at least partially controlled by physical cues. This agrees with results obtained by Lima and Pechenik (1985) in which they found that competent larvae will metamorphose in the presence of a suitable substrate for juvenile development. The sand grain composition of the egg capsule may also play a role in substrate recognition at metamorphosis. The adult may deliberately construct collars of sand of the desirable particle size for setting, knowledge of which is in some way imparted to the trochophore larva.

Some larvae did undergo metamorphosis in the bucket to which only algae was added. The food, visible in the gut tube of the swimming veligers, suggest that the larvae feed on algae during this stage of the life cycle. Other predatory marine gastropods feed on algae during the larval phase of their life cycle and switch to bivalve or to other prey after settlement (Brusca and Brusca 1990).

Future trials to induce metamorphosis of *E. heros* should include circulating water or raceway tanks (Nell *et al.* 1994), a substrate of sediment from the source of the collars and a diet of algae prior to settlement and small bivalve spat post-settlement.

There would appear to be little research on the effect of temperature on the embryonic development of marine gastropods (Lima and Pechenik 1985, Zimmerman and Pechenik 1991). Since temperature does have a direct effect on the metabolic rate of poikilothermic organisms, it could be hypothesized that increased temperature would raise the metabolic rate of embryonic gastropods, and increase their rate of development. Thomas and McClintock (1990) found that temperature had a dramatic effect on the length of embryonic development of larvae of the freshwater snail *Physella cubensis*. Maximum development was obtained at the maximum temperature within it's normal range. The larvae of *E. triseriata* hatched first at 18 $^{o}$C in all three egg cases. This would be near the upper limit of the temperature range that these larvae would normally experience in the water during the summer months. The results of this study indicate that it may be possible to accelerate the rearing time to hatch in *Euspira* through an increase in incubation temperature toward the maximum observed in the natural environment.

The successful hatching of the Unknown Canadian Species larva permits a tentative identification of this egg case as belonging to *Natica clausa*. This snail is in the same family as *Euspira* and is found commonly in Atlantic Canadian waters. The adult of this species is 2.5 to 3.5 cm in length. It has a thick white shell with a darker spot on the outermost whorl. The dark spot on *N. clausa* however is not black, which is the color seen on all of the unknown larvae. It is possible that the shell of the unknown larvae will lighten as it grows. The possibility of *N. clausa* being the parent snail to the type of egg case described in the paper was also suggested by Giglioli (1955). Further development of the larval snails into adult form must take place before the final determination of parentage can be made. Riddell (1995) provides color photographs of the Unknown Canadian Species hatchling.

The observed selection of similar sized prey in the juvenile stages is consistent with the view that the snails should select prey that will minimize their handling costs (Garton 1986, Stickle and Bayne 1987). Vencile (1997) conducted field and laboratory tests to determine prey size-selection in adult *E. heros*. Varying sizes and densities of moonsnails were offered five size classes of clams ranging from < 20 mm to > 50 mm in length. The results demonstrated that *E. heros* was a size-selective predator, consuming specimens of *Mya* which were less than 30 mm. Commito (1982) has also shown that *Mya arenaria* reach a size refuge from *Euspira heros* predation at about this size. However, field observations by Vencile (1997) showed a site specific influence on prey selection. Vencile (1997) suggests that the upper limit of prey size may be controlled by mechanical limitations.

Inadvertently, it was observed that *E. heros* adults could be held in flow-through tanks for extended periods (months) without food and lose very little weight. Other whelks have been found to fast throughout the summer months without losing a significant amount of weight (Himmelman and Hamel 1993). The implications of this characteristic to culturing are good with respect to holding and transport without loss of weight. Similarly, the fact that the moonsnails fed actively on dead fish simplifies feeding regimes for broodstock and long-term holding of product for market. The feeding of dead fish may impart a flavor to the meat and animals in pounds should only be fed live mussels, if necessary, prior to marketing.

## IMPLICATIONS FOR AQUACULTURE AND FISHERIES DEVELOPMENT

In 1998, moonsnails will be harvested along with the whelk, *Buccinum undatum*, under an exploratory fishery protocol. The animals are tasty and were a staple of the local Acadian diet in the last century. Moonsnails are often referred to as "sweet meats" by local consumers. Also, the large meat of the foot provides a high meat weight to shell weight ratio which is a desirable trait. Despite the palatability of the meat, several attempts to introduce it to the American market by Americans themselves, have been unsuccessful due to an aversion by the American public to eating "snails". The best price is likely to be obtained in Europe, where the consumer is more familiar with this form of shellfish.

The moonsnail is recognized as a choice bait product for longline gear and presently there is a license to harvest moonsnails for this purpose in Nova Scotia. As bait, moonsnails have been known to sell for $30 a bucket in Yarmouth, N.S. (D. Duggan, DFO, pers. comm.). Logbook data obtained from this bait license active in Port Joli, Nova Scotia are given in Table 1. Fishing began on August 15, 1997 and ended on September 5, 1997. Catches were at times very high with log records of 449 lb of 1.25-3.5 inch snails trapped in 24 hours (Table 1). The catch rate in terms of the number of moonsnails per trap per hour soak was initially low (0.5) but increased to a peak of 2.3 (Fig. 10). This catch rate was not sustainable at the Port Joli site at the fishing intensity and time of year for which data were available (Fig. 10). The by catch of crabs, and in particular rock crab, was much higher when fish was used as bait (Table 1, Fig. 11). High weight of rock crab in the traps corresponds to low catch rates of moonsnail (Fig. 11). This may be due to physical displacement, aggression behavior (on the part of the crab), avoidance behavior (on the part of the moonsnail), early consumption of bait or a combination of these and other factors.

Should interest develop in this fishery it would be practical to collect egg collars and introduce them to suitable habitat for enhancement or ranching, or to bring them to hatcheries for culture. Hundreds of egg cases have been collected from the shore on one tide (Wheatley 1947). The production of collars in the absence of sand and the emergence of healthy larvae from these same collars offers a unique opportunity to monitor the health of the developing larvae while in culture. As many parasites, including nematodes, inhabit the collars constructed of sand, sandless collars may also reduce the incidence of disease outbreak in captivity. While the life cycle of the moonsnail was not completed during this study, the similarity of the development to other culture species such as the oyster and scallop, suggests that this would be a feasible task.

## ACKNOWLEDGEMENTS

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Table 1. Summary of 1997 Logbook Information for *Euspira heros*.

| **Port Joli, Nova Scotia**<br>Location: Lat. 43 51.01 Long. 64 57.00 Loran C 13490.1 30640.9 |
|---|
| August 15, 1997<br>No. of Pots: 10 Bait: fresh fish cuttings<br>Soak Time: 12 hrs<br>Number of Moonsnails: 12<br>Weight: 5 lb Size: 1. 5 - 3.5 inches<br>By Catch: Rock crab 50 lb. |
| August 25, 1997<br>No. of Pots: 25 Bait: ocean quahog<br>Soak Time: 12 hrs<br>Number of Moonsnails: 679<br>Weight: 225 lb Size: 1.25 - 3.5 inches<br>By Catch: Rock crab 10 lb.; Green crab 5 lb. |
| August 27, 1997<br>No. of Pots: 50 Bait: ocean quahog, Stimpson's surfclam<br>Soak Time: 12 hrs<br>Number of Moonsnails: 1196<br>Weight: 402 lb Size: 1.25 - 3.5 inches<br>By Catch: Rock crab 15 lb. |
| August 29, 1997<br>No. of Pots: 50 Bait: ocean quahog, Stimpson's surfclam<br>Soak Time: 24 hrs<br>Number of Moonsnails: 1348<br>Weight: 449 lb Size: 1.25 - 3.5 inches<br>By Catch: Rock crab 12 lb. |
| September 1, 1997<br>No. of Pots: 25 Bait: northern propeller clam<br>Soak Time: 12 hrs<br>Number of Moonsnails: 295<br>Weight: 98 lb Size: 1.25 - 3.5 inches<br>By Catch: Rock crab 4 lb. |
| September 5, 1997<br>No. of Pots: 25 Bait: fresh mackeral<br>Soak Time: 12 hrs<br>Number of Moonsnails: 155<br>Weight: 53 lb Size: 1.25 - 3.5 inches<br>By Catch: Rock crab 100 lb. |

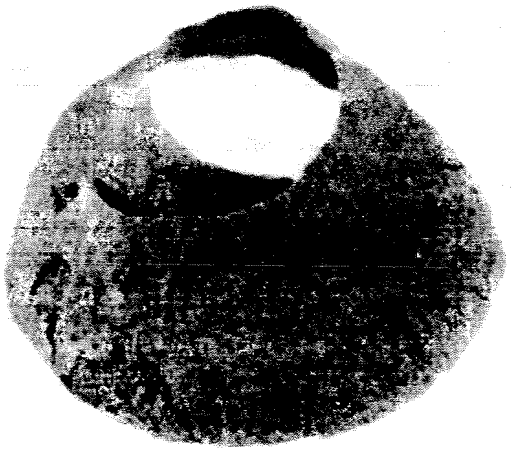


Figure 4. *Euspira heros*. Egg case of the moonsnail.

Figure 5. *Euspira heros*. Adult specimen with foot extended.

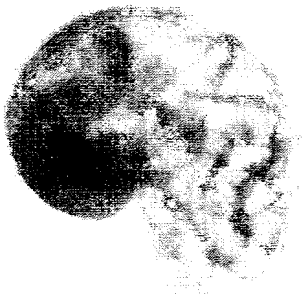
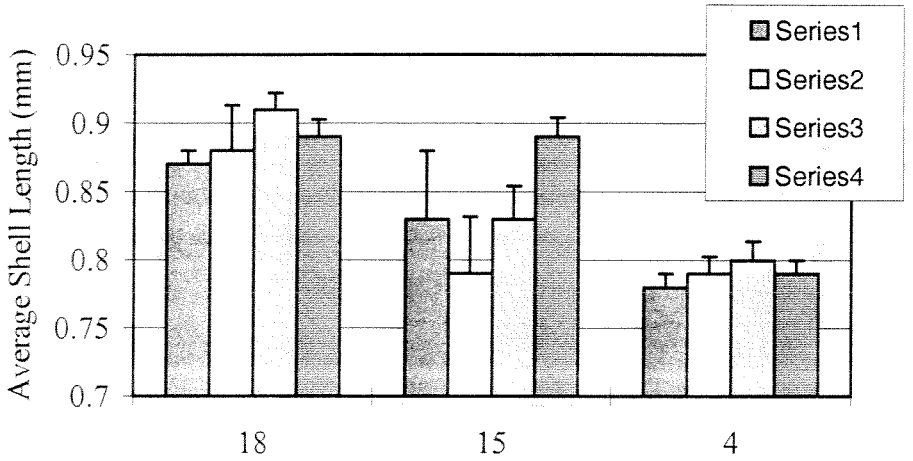
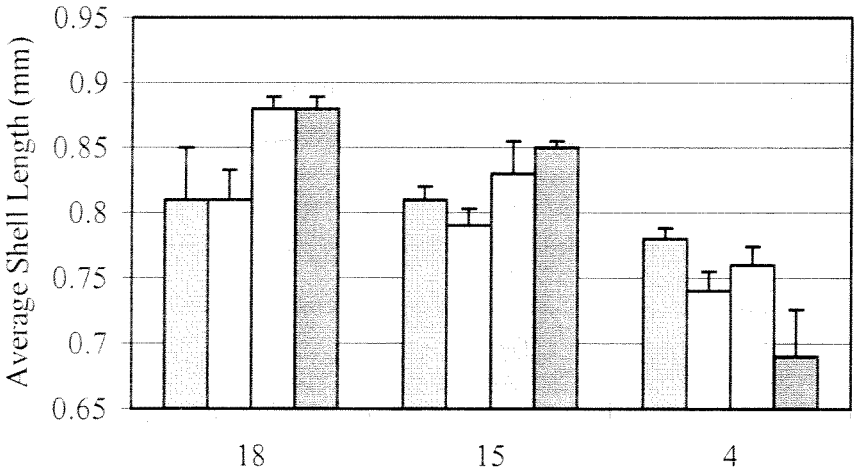


Figure 6. *Euspira heros*. Veliger at hatch with foot and gut tube visible. Approximate size 284 um.

**EGG CASE A**




**EGG CASE B**




**EGG CASE C**

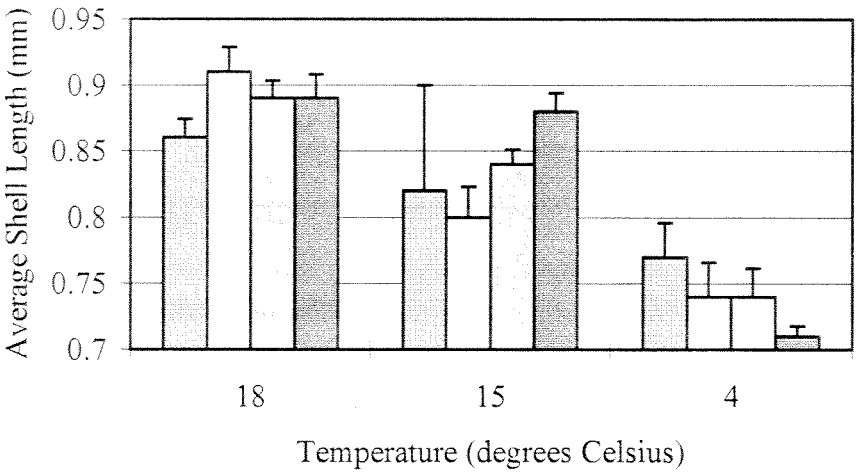



Figure 7. *Euspira triseriata*. Average length (plus one standard error) of intracapsular larvae from Egg Cases A, B, and C under three temperatures over 4 weeks (Series).

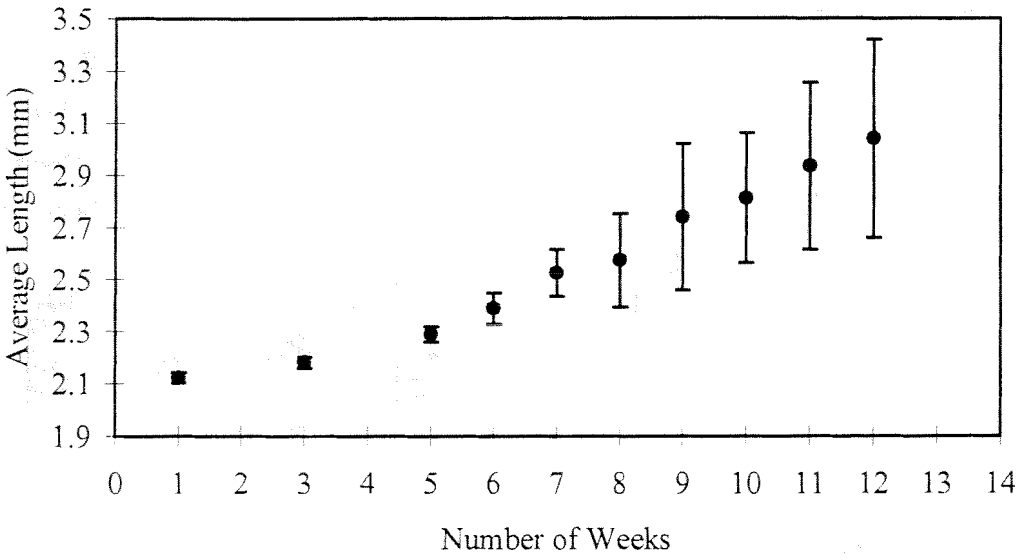



Figure 8. Unknown Canadian Species. Growth rate of larvae over 12 weeks of observations post hatch. The mean and standard error are indicated on the graph for each observation date.

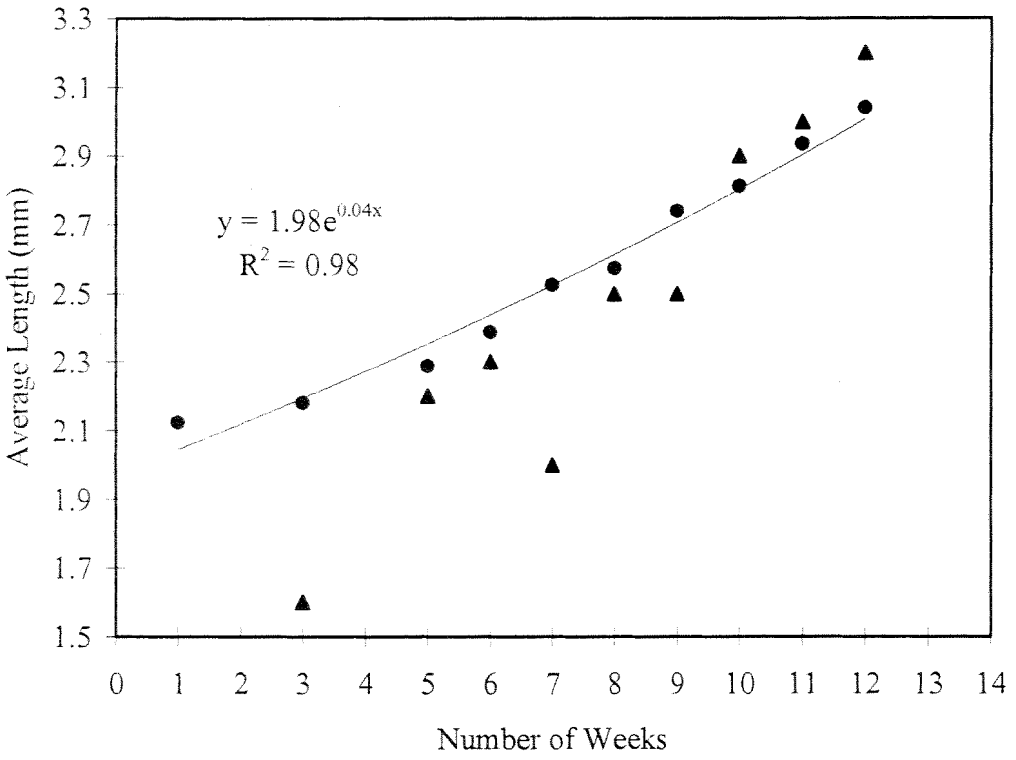



Figure 9. Unknown Canadian Species. Average size of moonsnail larvae (solid circle) in relation to the average prey (mussel spat) size (solid triangle) over 12 weeks of observations post hatch. An exponential regression through the moonsnail growth data is illustrated with equation.

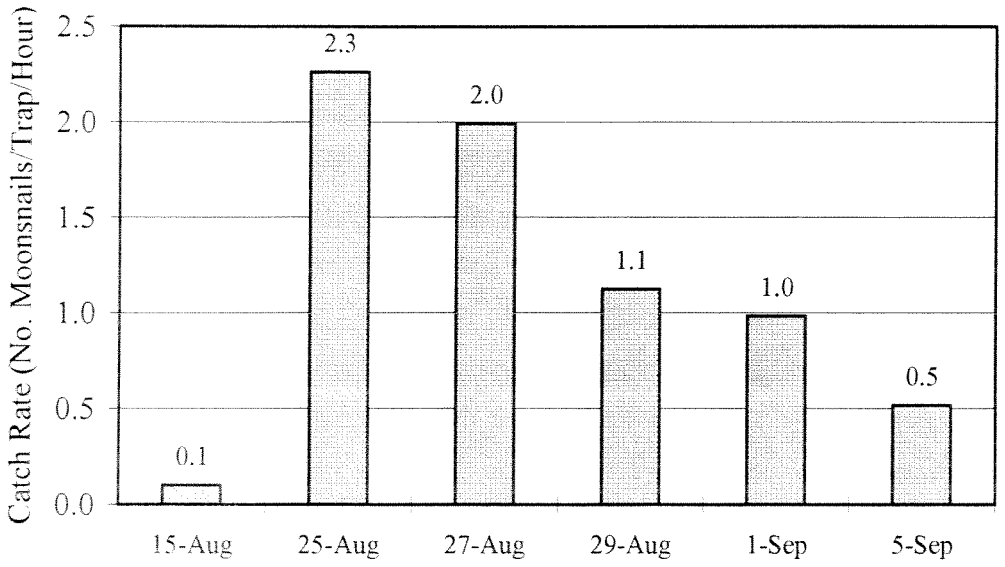



Figure 10. *Euspira* spp. Port Joli, Nova Scotia. Catch rate in terms of the number of moonsnails per trap per hour soak (Table 1).

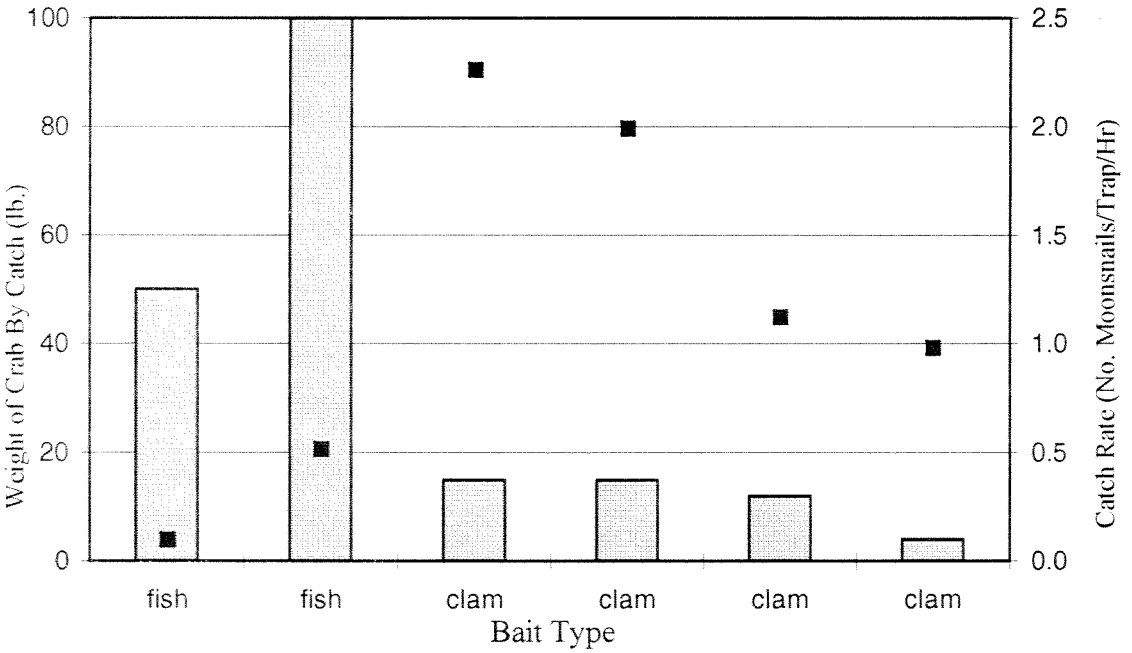



Figure 11. *Euspira* spp. Port Joli, Nova Scotia. Catch rate in terms of the number of moonsnails per trap per hour soak (solid square) and the weight (lb.) of the crab by catch with respect to bait type.