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Canadian Stock Assessment Secretariat
Research Document 99/193

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/193

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Distribution, Abundance, Biology and Fisheries Potential of the Exotic Varnish Clam (*Nuttallia obscurata*) in British Columbia

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ISSN 1480-4883
Ottawa, 1999

Canada

ABSTRACT

Varnish clams, *Nuttallia obscurata*, have recently become established in Georgia Strait, and have been found in Barkley Sound on the west coast of Vancouver Island and estuaries in Oregon. They are dispersing southward into Puget Sound, and could spread northward into the Central Coast, similar to Manila clams.

This paper discusses distribution and dispersal of varnish clams and collects available information on biology, ecology and population dynamics (from the literature and other sources). This information is summarized, and gaps in required information are identified. The fishery potential, management approaches and assessment information requirements to develop and evaluate the effectiveness of management tactics are discussed. The paper suggests that varnish clams have potential as commercial and recreational resources, and should be managed accordingly.

RÉSUMÉ

La palourde *Nuttallia obscurata* s’est récemment établie dans le détroit de Géorgie et a été décelée dans le détroit Barkley, sur la côte ouest de l’île de Vancouver, ainsi que dans des estuaires de l’Orégon. L’espèce se disperse en direction sud, dans le Puget Sound, et pourrait aussi se déplacer en direction nord, pour atteindre la Côte du centre, comme la palourde japonaise.

Le document traite de la répartition et de la dispersion de *Nuttallia obscurata* et présente les renseignements obtenus, à partir de la littérature ou d’autres sources, sur la biologie, l’écologie et la dynamique de population. L’information est résumée et les carences sont précisées. On y traite des possibilités de pêche, des démarches de gestion et des besoins d’information en matière d’évaluation nécessaires à l’élaboration et à l’évaluation de l’efficacité des modes de gestion. Il semble que cette palourde pourrait constituer une ressource pour les pêches commerciale et récréative et devrait donc être gérée en conséquence.

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INTRODUCTION

Exotic Molluscs in British Columbia – A Brief Review

The occurrence and implications of introductions of exotic molluscs have attracted increased attention in the 1990's (*e.g.*, Carlton 1992; Carlton and Geller 1993; Elston 1997). The main activities that serve as avenues of transport of exotic molluscs can be broadly grouped into five categories (Carlton 1992):

- transport on the outside (fouling organisms) or inside (boring organisms) of ships;
- transport inside vessels in solid ballast, such as rock, sand and detritus;
- movement of oysters, with inadvertent transport of organisms on the oyster shells or in associated sediment and detritus;
- intentional release of species for fisheries purposes;
- release of larvae, juveniles or adult marine organisms through release of ballast water from vessels originating in foreign ports; and
- accidental release by the public.

With the possible exception of the second category, all of these activities have contributed to the present fauna of British Columbia (B.C.).

British Columbia has a long history of introduction and invasion of molluscs related to development of oyster culture (Table 1) (Quayle 1988, Carlton 1992, Gillespie 1999b). The difference between "introduction" and "invasion" is merely one of intent: the former are deliberate and desired events, the latter are unintentional or accidental. Pacific, *Crassostrea gigas*, Atlantic, *Crassostrea virginica*, and European flat oysters, *Ostrea edulis*, have all been introduced to B.C. for culture. Pacific oysters are established in Georgia Strait and the west coast of Vancouver Island (Quayle 1988). Atlantic oysters are only established in the Nicomekl River estuary in Boundary Bay, where they have maintained populations in the absence of renewed introduction for many years. Reports of wild sets of European flat oysters in Barkley Sound imply that successful breeding has occurred, but permanent establishment is not certain (Gillespie 1999b). Japanese weathervane scallops, *Mizuhopecten yessoensis*, are cultured on-bottom in Georgia Strait and have been introduced to aquaculture pilot sites in northern B.C., but are not known to have established populations. Reports of northern quahogs, *Mercenaria mercenaria* from California (Carlton 1992) and Boundary Bay (Forsyth 1997; Turgeon *et al*. 1998) are believed to be intentional introductions. Bay mussels, *Mytilus edulis* and *Mytilus galloprovincialis*, have established populations in B.C., the former perhaps due to unintentional introductions, the latter as wild settlement from aquaculture endeavours (Gillespie 1999a). Either species may have come to B.C. as fouling organisms on ship hulls.

Other species have found their way into B.C. waters as invaders, either through unintentional introduction along with desired species, through ballast water, or naturally invading following introduction elsewhere (Table 1). Several Japanese species became established, either locally or widespread, with Pacific oyster seed. Japanese green mussels, *Musculista senhousia*, were known from Puget Sound since the 1940's (Abbott 1974), and have recently been recorded from a number of sites in Georgia Strait (Forsyth 1993; Merilees and Gillespie 1995). Carlton (1992) linked the appearance of *Musculista* in southern California in the 1970's to ballast water introduction; it is possible that recent expansion of the species in Georgia Strait might represent recent introductions, and not expansion from historic introductions in Puget Sound. Japanese rocksnails, *Ocinebrina inornata* [= *Ceratostoma inornatum*, *Ocenebra japonica*[1]], Japanese nassa, *Nassarius fraterculus*, and quadrate trapezium, *Neotrapezium liratum*, are locally common at relatively few sites (Quayle 1964; Carlton 1992), while Japanese false cerith, *Battilaria attramentaria* [= *B. zonalis*], are widely established in B.C. (Quayle 1964; Harbo 1997). Atlantic oyster drills, *Urosalpinx cinerea*, eastern mudsnails, *Nassarius obsoletus*, convex slippersnails, *Crepidula convexa*, European ovatella, *Myosotella myosotis*, and false angelwings, *Petricolaria pholadiformis*, are locally established in B.C., invading with introduced Atlantic oysters (Carlton 1992). Eastern softshell clams, *Mya arenaria*, which became extinct on the Pacific coast in the late Tertiary, spread north through B.C. into Alaska from San Francisco Bay after re-introduction along with Atlantic oysters in the late 1800's (Quayle 1964; Bernard 1979). The Atlantic shipworm, *Teredo navalis*, is believed to have arrived in B.C. in wooden ships (Quayle 1964), and the Japanese shipworm, *Lyrodus takanoshimensis*, was transported to B.C. in wooden crates containing Pacific oyster seed (Carlton 1992). Manila clams, also called Japanese littlenecks, *Venerupis philippinarum*, were accidentally introduced into Ladysmith Harbour along with Pacific oyster seed in the 1930's, quickly established populations throughout Georgia Strait and the west coast of Vancouver Island, eventually spreading to the Central Coast (Quayle and Bourne 1972; Bourne 1982). They eventually became the primary target of commercial clam fisheries in B.C. (Webb and Hobbs 1997).

Varnish clams, *Nuttallia obscurata*, are exotic bivalves that have recently become established in B.C., likely through introduction in ballast water. Little information is available on the species within its native range in the northwestern Pacific, and less in the northeastern Pacific. This document synthesizes available literature and information from unpublished work to develop a summary of biological and ecological information, identify and discuss gaps in knowledge, explore the fisheries potential of the species, and present options for development of rational, biologically-based management objectives for a varnish clam fishery in B.C. This represents completion of phase 0 of the framework for development of new invertebrate fisheries as outlined by Perry *et al*. (1999).

THE VARNISH CLAM

Taxonomy

The varnish clam is one of three species of *Nuttallia* native to the northwestern Pacific; the others are *N. japonica* and *N. ezonis* (Coan 1973; Roth 1978). Originally described as *Soletellina obscurata* Reeve, 1857, the varnish clam's synonymy includes the junior synonyms *Psammobia olivacea* Jay, 1857 and *Nuttallia solida* Kira, 1953, and incorrect inclusion by some authors in the taxon *Soletellina japonica* Reeve, 1857 (Roth 1978; Coan *et al*., in press). Turgeon *et al*. (1998) used the common name purple mahogany-clam.

[1] Scientific names follow Turgeon *et al*. (1998)

Nuttallia was formerly considered a subgenus of *Sanguinolaria*, a genus characterised by elongate, brightly coloured shells, which is not found in the northeastern Pacific (Coan *et al*., in press). The varnish clam's closest relative in North America is the California mahoganyclam, *Nuttallia nuttalli* (=*Sanguinolaria nuttalli*), which is found from Bodega Bay, California, to Magdalena Bay, Baja California (Fitch 1953; Coan *et al*., in press).

One other member of the family Psammobiidae is found in B.C., the California sunsetclam, *Gari californica* (Harbo 1997). The painted sunsetclam, *G. furcata*, the green sunsetclam, *G. regularis*, and the Pacific false beanclam, *Heterodonax pacificus*, are other psammobiid clams found from California southward (Coan *et al*., in press).

Description

Varnish clams (Figure 1) have compressed valves, nearly oval in outline, the height of the shell is approximately 0.80 of the shell length, and the thickness approximately 0.35 of the shell length. Both ends of the shells are rounded, the posterior longer and more angular than the anterior. Outer surfaces of the valves are covered with a thick, shiny brown periostracum, often eroded to expose the chalky, purplish-white shell near the umbo. The valves are unequally inflated, the right valve flatter than the left, though more equally convex than in *N. nuttalli* or *N. japonica*, both of which have distinctly flattened right valves (Fitch 1953; Roth 1978). The hinge ligament is external and large. Smaller specimens may be light tan in color, exhibiting dark purple rays from the umbo to the margin or may be uniformly dark brown or dark purple.

The interior surface is purple, ranging from deep royal purple to light violet in different individuals. The purple fades as the shell dries, and older dead shell may appear white inside. Less than 1% of varnish clams examined by us lacked purple pigment and were white or yellowish inside the valves. These individuals had a noticably lighter periostracum (colloquially termed "blondes"). The anterior adductor muscle scar is long and vaguely crescentic. The posterior muscle scar is nearly rectangular in outline. The pallial sinus, which is obliquely oval, narrowing on the dorsal margin to become somewhat angular anteriorly, extends anterior to a position directly beneath, or very slightly anterior to, the umbo. The ventral margin of the sinus extends posterior to a point directly beneath the posterior margin of the posterior adductor scar. The body, foot, siphons and mantle are white. The siphons are long and separate for their entire length, with six simple papillae and a muscular sphincter at the terminal opening (Parker and Reid, unpublished manuscript).

Sakai and Sekiguchi (1992) provided photographs and illustrations of larval *Nuttallia olivacea* (= *N. obscurata*). The larvae resemble those of Manila clams, but have the umbo much less pronounced at a given size. The large external ligament is quite obvious by a size of 0.5 mm.

Maximum size recorded by us was 64 mm TL, weighing 45.1 g, taken at Newcastle Island, Nanaimo in 1998. Maximum size observed at Fidalgo Bay was 68 mm TL (P. Dinnel, Western Washington University (WWU), pers. comm.). This is considerably smaller than the maximum size of 150 mm TL reported for the closely related *N. nuttalli* (Coan 1973). It may be larger than the species grows in the northwestern Pacific (G. Jamieson, Pacific Biological Station, pers. comm.)

Distribution

Geographic Limits

Varnish clams are native to Korea and the Japanese islands of Kyushu, Honshu and Shikoku (Coan *et al*., in press). In B.C., they are established throughout Georgia Strait (Forsyth 1993, 1997; Gillespie 1995; Merilees and Gillespie 1995; Nichol *et al*. 1999) and have been found in Barkley Sound on the west coast of Vancouver Island (Nichol *et al*. 1999). In Washington State, they have been reported from northern Puget Sound to approximately Port Townsend (48°01'N) (Yates 1999), and are steadily dispersing southward. They have been reported from most of the major estuaries of Oregon (J. Johnson, ODFW, pers. comm.), but have not been reported from Willapa Bay or Grays Harbour, WA, or from California. Current latitudinal limits are Manson's Lagoon, Georgia Strait (50°04'N) and Alsea Bay, OR (44°04'N) (Gillespie 1995; Coan *et al*., in press).

Habitat

The shell and body form of varnish clams provide clues as to their habitat (Purchon 1968). The smooth shell, oval in outline and laterally compressed, and large active foot are typical of active burrowing bivalves. The long siphons and deep pallial sinus indicate an ability to exist deep in the substrate.

Varnish clams were most often encountered on beaches of mixed sand, gravel and mud substrates. They were usually found in greatest abundance higher on the beach than either native littleneck, *Protothaca staminea*, or Manila clams, or in areas of significant freshwater influence such as stream channels or freshwater seepage through the beach. They were most numerous in the estuarine channels at Departure Bay, and associated with freshwater outflows at the Englishman and Little Qualicum River Estuaries and at Bamberton Provincial Park (W. Austin, Khoyatan Marine Laboratories, Cowichan Bay, pers. comm.). They were situated in an area of groundwater seepage at approximately the 2 m tide level on Newcastle Island. On beaches which lacked freshwater runoff (*e.g.*, Dunsmuir Islands) they were found higher on the beach than the main concentrations of Manila and littleneck clams, usually on the peak of ridges of sand/gravel substrate.

Samples were taken at different tidal elevations in Departure Bay in July 1997, using a metal cylinder (approximately 0.05 m^2), and passing the sampled substrate through a 1 mm screen. We found varnish clams from approximately the 3.0 m tide level to low water (1.1 m), with peak abundance (89 clams in the sample, or 1,780 clams/m^2) at 1.66 m above chart datum (Figure 3). Length frequency distribution of the sample was dominated by small, presumably young varnish clams. The extremely high density was a function of use of screens to collect small clams, and reflected either high settlement rates or low post-settlement mortality.

At Savary Island in 1996, varnish clam abundance was greatest in the upper third of the survey area, and decreased to the middle and lower beach (Table 2). These estimates include a significant settlement event (see Figure 4, lower panel), and densities in the lower two-thirds of the beach may represent new recruits that had not yet suffered the full effects of post-settlement mortality.

In relatively soft substrates, varnish clams orient vertically, posterior-upwards, at depths of seven to at least 30 cm in the substrate. In rougher substrates, the clams were often skewed from the vertical, fitting around the larger gravel and rocks. This vertical orientation is in contrast to *N. nuttalli*, which are found oriented horizontally, lying on the flattened right valve (Fitch 1953).

Yates (1999) examined clam size relative to depth inhabited in the substrate. Her expectation was that smaller clams, with shorter siphons, would be positioned shallower in the substrate and larger clams deeper, as reported for *Soletellina violacea* in India (Yeragi 1991). Most clams were found between 12-26 cm depth in the substrate, with no clear relationship between clam size and depth, but rather a "shotgun distribution" (P. Dinnel, WWU, pers. comm.).

Biology

Reproduction

Varnish clams are synchronous broadcast spawners, with planktonic larvae (Tsutsumi and Sekiguchi 1996). In Japan, newly settled larvae were found on tidal flats in association with larval Manila clams, mytilid and green mussels, and the bivalves *Mactra veneriformis*, *Meretrix lusoria*, *Alvenius ojianus*, and *Teredo navalis* (Sakai and Sekiguchi 1992). In the northwestern Pacific, varnish clams mature in 1 year, and spawn once per year in early May (Hushan 1994).

Seasonality of spawning, duration of a planktonic larval period, and season of settlement have not been determined in the northeast Pacific. The rapid establishment of a widespread population within Georgia Strait and continued expansion into Puget Sound imply the presence of moderately long larval period (possibly 3-4 weeks, as in Pacific oysters or Manila clams). Lack of the smallest size classes in Yates' (1999) samples, taken in February, and the large contribution of clams <10 mm TL from the May 1996 samples taken at Savary Island, although both surveys used screens to specifically search for recruits, could indicate an early spring settlement time in Georgia Strait/Puget Sound. Parker and Reid's (unpublished manuscript) observation of 1-2 mm TL varnish clams at Bamberton in October 1996 is consistent with spring/summer reproduction.

Feeding

Varnish clams are members of the Tellinacea, a group ranging from selective suspension feeding (Donacidae), through unselective suspension feeding (some Donacidae, Solecurtidae and

Psammobiidae) to specialized deposit feeders (Scrobiculariidae, Tellinidae and Semelidae) (Pohlo 1982). Pohlo (1972) listed several anatomical features that generally characterized suspension and deposit feeding tellinacean clams:

- suspension feeders have small labial palps relative to the demibranchs, deposit feeders have large palps and small demibranchs;
- the outer demibranch lies adjacent to the inner demibranch in suspension feeders, but is upturned in deposit feeders;
- a mantle fold on the anterior margin of the inhalant siphon is absent in suspension feeders, but present in deposit feeders;
- straining tentacles are present on the inhalant siphon of suspension feeders, absent in deposit feeders;
- a food groove is present on the inner demibranch of suspension feeders, absent in deposit feeders; and
- suspension feeders are oriented vertically in their burrows, deposit feeders lie on their side.

He noted that the morphology of *N. nuttalli* was largely consistent with suspension feeding (large demibranchs, small palps, upper demibranch not upturned, mantle fold absent) with two exceptions: straining tentacles on the inhalant siphon were absent, and *N. nuttalli* lies on its side in the substrate (Pohlo 1972, 1982). Observations of feeding behaviour indicated that the inhalant siphon was not normally extended above the level of the substrate, was inactive, and was never observed to actively ingest deposits. Some individuals had little or no sand in the mantle cavity, while others had considerable amounts; similarly, some had no sand in the stomach contents, while other had sand in their stomachs. Food material was primarily diatoms, flagellates and amorphous green debris. He categorized *N. nuttalli* as a non-selective suspension feeder, hypothesizing that sand in the mantle and stomach was a result of deposits falling into the inhalant siphon (which lacks straining tentacles), and being passed into the stomach if small enough.

Tsuchiya and Kurihara (1980) reported *N. olivacea* [= *N. obscurata*] to be siphonal deposit feeders, extending the inhalant siphon over wide areas of the substrate to take up deposited materials. The related Indian species *Soletellina violacea* was reported to be a siphonal detritus feeder (Yeragi 1991). Stomach contents included animal remains, algal fragments, sand and detritus.

Parker (unpublished manuscript) and Parker and Reid (unpublished manuscript) explored feeding behaviour and morphology of varnish clams in B.C. They noted that the labial palps were larger than in Pohlo's (1972) description and figure of *N. nuttalli*, the outer demibranch was not reflected, and there were no food grooves on the margins of the demibranchs. Stomach contents included diatoms, bacteria, macroalgal fragments, small wood fragments and silt.

When observed in the substrate in a laboratory setting, varnish clam siphons were more often exposed at night, and held vertically above the substrate. They were not observed to rotate over the substrate, nor to contact the substrate to ingest deposit material (Parker; Parker and

Reid, unpublished manuscripts). They observed varnish clams to utilize locomotory and pedal-sweep feeding. In the first method, the foot was extended for locomotory puposes, and cilia on the foot collected detritus and passed it to the oral region. In pedal-sweep feeding, the foot was extended and rotated anteriorly. Deposit materials ascended the foot on ciliary currents and were introduced into the oral region when the foot was retracted.

Age and Growth

Age determination by interpretation and counts of annuli on the valve surface, as is used to estimate ages of hardshell clams (Quayle and Bourne 1972), has proved difficult to apply to varnish clams. Some clams collected from clean sand habitats exhibit fairly clear patterns, but clams from gravel or mixed substrate habitats exhibit numerous checks (circuli that are laid down in response to disturbance of growth, not linked to annual growth patterns). To date, all efforts to examine age structure of varnish clam populations have relied on interpretation of length frequency distributions.

Parker and Reid (unpublished manuscript) estimated that the 1995 year class of varnish clams at Bamberton had grown to 10-20 mm TL by August of 1996, and noted the appearance of numerous juveniles, 1-2 mm TL, in October 1996. Yates (1999) estimated that as many as five year classes might be represented at Fidalgo Bay in Puget Sound from surveys in February 1999. Approximate mid-range lengths were 17 mm, 25 mm, 33 mm, 43 mm and 53 mm, representing her estimated age classes 1-5, respectively.

Biological data collected incidentally during Manila clam surveys at Savary Island between 1996 and 1999 show the following patterns. Small varnish clams were noted as being present, but not sampled in April 1995 (Gillespie *et al*. 1998). The May 1996 length frequency distribution showed two modes, one of clams <10 mm TL, and one broadly centered around 19 mm TL (Figure 4). These modes possibly represent the 1996 and 1995 year classes. Larger clams representing earlier year classes may be under-represented in these samples, as samples were not taken as part of a comprehensive survey, and came from closer to the center of the beach, while the few large clams seen in 1995 were near the ends of the beach. The April 1997 length frequency distribution had modes at approximately 17, 26, 31 and 46 mm TL (Figure 5), possibly representing age classes 1-3 and 5. The 1998 length frequency distribution could represent age classes 1-4, with modes at 16, 22, 30 and 37 mm TL (Figure 6). The April 1999 length frequency distribution could represent age classes 0-3 with modes at 11, 22, 27 and 32 mm TL (Figure 7).

When Savary results are compared to Yates' (1999) data from Fidalgo Bay, it appears that varnish clams at Savary Island may grow slower than in Puget Sound (Table 3, Figure 8). Note that the mean growth rate at Savary Island was calculated over a number of years, during which varnish clam abundance increased dramatically. If density-dependent growth effects exist, then these will affect the mean length-at-age relationship. In both data sets, samples were taken across a wide range of tidal elevation, which could have affected growth rates. Although the data represented here are purely qualitative, they would appear to indicate that varnish clams grow at a rate similar to Manila clams at Savary Island (Gillespie *et al*. 1998), requiring approximately four years to reach 38 mm TL.

Length-weight relationships were calculated for Manila and varnish clams from April 1998 Savary Island samples (Figure 9). Both relationships were roughly cubic, with high R^2 values. When the derived relationships were plotted together, it was obvious that varnish clams did not weigh as much for a given length as Manila clams, as would be expected for a thinner species with a lighter shell (Figure 10).

Population Dynamics

Anecdotal information from clam harvesters, culturists and naturalists indicated that varnish clams have quickly established large populations on suitable beaches in B.C. Settlement can be generally distributed over beaches, as seen at Departure Bay (Figure 3), with post-settlement processes determining adult distribution (Peterson 1986; Olafsson *et al*. 1994). If the length-based age classes presented above and in Yates (1999) are valid, then recruitment appears to be variable.

Intertidal clam assessments were completed at Savary Island in 1995, 1997 and 1999. In 1995, recently set varnish clams were observed, but population estimates were not made (Gillespie *et al*. 1998). Varnish clam data were collected in 1997 and 1999, and can be compared with Manila and littleneck data from the same surveys.

Density of varnish clams increased approximately four-fold between 1997 and 1999, exceeding Manila clam density (Figure 11, upper panel). Manila density increased between 1995 and 1997, and remained at roughly the same level in 1999. This was due to increased sublegal density that compensated for reductions in legal size Manila clams, due in part to fishery removals (Figure 11, lower panel).

These data indicate that significant Manila clam recruitment has occurred during the period of varnish clam population increases, although these increases could be due to clams that set before the varnish clam population increased, that may not have been detected due to size selectivity of the survey method. Continuation of this data series would assist in monitoring interactions between Manila and varnish clam populations.

Ecological Relationships

Associated Species

Varnish clams are most common in upper to middle intertidal bivalve communities. At Departure Bay they were associated primarily with Manila clams, with a small number of littleneck, eastern softshell and butter clams (*Saxidomus gigantea*). At Savary Island and Mittlenatch Island, Manila, littleneck and *Macoma* sp. were found in the same quadrats. Parker and Reid (unpublished manuscript) observed *Nuttallia* in association with cockles, littleneck, Manila and softshell clams, *Macoma nasuta*, *M. inquinata*, *M. balthica* and *Tellina* sp. at Bamberton, Saanich Inlet, B.C.

Symbionts/Parasites

Varnish clams often host a native pinnotherid pea crab, *Pinnixia faba* (Gillespie 1995; Harbo 1997). Immature *P. faba* have been recorded from numerous clam species native to British Columbia, including the confamilial sunsetclam, *Gari californica*, and exotic Manila and eastern softshell clams (Hart 1982).

Soong (1997) reported 90% infection of symbiotic pea crabs, *Pinnotheres tsingtaoensis*, from the psammobiid clam *Sanguinolaria acuta* in Taiwan. The crabs were specific to the clam host, as other clams collected (*Solen* and *Laternula*) were not infected. The crabs matured and reproduced within *S. acuta*.

We examined varnish clams for pea crab infection at Departure Bay, Nanaimo, between December 1998 and September 1999 (Table 4, Figure 12). Infection rates were highest in December (0.75) and lowest in September (0.17). Infection was usually by a single pea crab, 2 crabs were seen in 0.2% of clams examined (5 of 2,417). We did not record male:female ratio, but males greatly outnumbered females. All crabs were immature – no females brooding eggs were observed. Hart (1982) noted that immatures occur in many bivalve species, but mature pairs are found only in the horse clam, *Tresus capax*.

Predators

Merilees and Gillespie (1995) noted one specimen from Cortes Island that was prey of Lewis' moonsnail, *Euspira lewisii*, and Parker and Reid (unpublished manuscript) observed moonsnail predation of varnish clams at Bamberton. B.C. Subsequent investigations in Departure Bay and elsewhere have shown that moonsnail predation is common.

Bernard (1967) examined clam predation by moonsnails, and noted consistent positioning of drill holes in predated cockle, Manila, littleneck and horse clams. The left valve was selected more often than the right, and the vast majority of drill holes were immediately ventral to the umbo (Table 5).

Merilees (unpublished data) examined hole location on shells of varnish clams collected at Shark Spit, Marina Island and littleneck clams collected from Rathtrevor Beach. Shell dimensions and drill location were measured, and standardized to proportions of total length. Standardized drill locations were plotted, and those holes that fell within the quadrant of the shell containing the umbo were scored as "near" the umbo, while holes in other quadrants were scored as "away" from the umbo. When compared to more traditional prey species, the site of drilling on varnish clams by the snail is more variable (Table 5). Littleneck results from Rathtrevor Beach were very similar to Bernard's (1967) results, with 72% drilled on the left valve, and 100% drilled near the umbo. Forty-one percent of varnish clams were drilled on the left valve, with 73% of drill holes located near the umbo.

In early surveys varnish clams were not observed as regular prey of glacous-winged gulls, *Larus glaucescens*, or northwestern crows, *Corvus caurinus* (Gillespie 1995) These predators would regularly examine quadrat locations for excavated clams, which were then carried off to be dropped and broken. Although they quickly accepted littleneck, Manila, butter clams and cockles, they avoided varnish clams. They have since recognized varnish clams as prey, and varnish clam shell is regularly found broken on the walkway above the beach.

Black oystercatchers, *Haematopus bachmani*, have been observed to prey on varnish clams in Departure Bay. They probe the sand with their bills at the tide line, often in channels of the creek. When they encounter varnish clams, they seize them in their beak, turn their entire bodies 90% to their original orientation, and pull the clam from the substrate. They then insert their beak between the valves, either cutting the adductor muscles or ripping them by prying the shells apart. The soft parts are then pulled out and consumed. The remaining shells are clean except for fragments of adductor muscle. The entire process from discovery to resumption of searching takes <30 seconds, and if clams are abundant, oystercatchers can capture and process 1-2 clams/minute.

Crabs are expected to be a predator of varnish clams, as they prey on small clams of other species. Yates (1999) observed a negative correlation between varnish clam abundance and presence of juvenile Dungeness, *Cancer magister*, and helmet crabs, *Telmessus cheiragonus*, in Padilla Bay, Puget Sound. She surmised that the presence of predators, in addition to substrate composition, may be important determinants of varnish clam density. The varnish clam's ability to live in the upper intertidal zone likely provides refuge from predation by most species of crab, including all *Cancer* species. Shore crabs, *Hemigrapsus* sp., may prey on small varnish clams high on the beach.

The lower extent of successful recruitment may be a function of the tolerances of predatory crabs and moonsnails, similar to the relationships of mussels and their predators on rocky shores (Gillespie 1999a).

Fishery Potential

Varnish clams have the potential to be a commercially valuable food species. They are an attractive clam, with a shiny brown periostracum and purple inside the valves, which contrast well with the white body mass. The body fills the shell, and can be easily separated from the valves after steaming.

The closely related *Nuttallia nuttalli* is not harvested commercially in California. Fitch (1953) indicated the species, although commonly available and good-tasting, was harvested primarily for fish bait, not human consumption. The related species *Soletellina diphos* is cultured in Taiwan (Hwang *et al*. 1987, 1989, 1990, 1992), and *Soletellina violacea* has been proposed as a potential aquaculture resource in India (Yeragi 1991).

A small quantity of product was test marketed in 1998 from aquaculture tenures in Baynes Sound (Heath 1998). Market response was favourable, and the price for varnish clams was about 30% less than Manila clams (R. Webb, DFO Fish Management Branch, Parksville, pers. comm.). The preferred size was similar to that of Manila clams (38-44 mm), and the meat yield was higher. The processor did not experience problems with breakage, but the harvesters noted that they packed varnish clams into sacks of ~12 kg (25 lb), rather than the 18 kg (40 lb) sacks used for Manilas. There was no assessment of losses due to breakage during digging.

Further harvests were curtailed pending satisfaction of Canadian Food Inspection Agency (CFIA) shellfish safety requirements. Limited testing was undertaken by CFIA in 1998 to determine PSP and faecal coliform accumulation and depuration characteristics of varnish clams. Parameters were similar to those for Manila clams and Pacific oysters. CFIA intends to include more comprehensive testing in conjunction with pilot projects exploring fishery development (K. Schallie, CFIA, pers. comm.).

The cultured psammobiid clam *Soletellina diphos* was responsible for outbreaks of PSP-related illness in Taiwan in 1986 and 1991, including two deaths in the first case (Hwang *et al*. 1987, 1989, 1990, 1992; Cheng *et al*. 1991). The toxins identified were gonyautoxins 1-4, with traces of saxitoxin and neosaxitoxin, implicating dinoflagellates as the source (Hwang *et al*. 1987). The digestive gland was the major site of accumulation, with the siphons and other tissues less toxic. Hwang *et al*. (1989) noted that the digestive glands retained some toxins for at least one year, and the pattern of rapid accumulation and long retention time more closely resembled scallops than other clams, which eliminated toxins from the digestive gland relatively quickly. Butter clams do store toxins for significant periods of time, but the toxins accumulate primarily in the siphons (Quayle 1969).

Yates (1999) described steamed varnish clams as similar to Manila and littleneck clams, in both taste and texture. Some larger clams have been described as having an unpleasant "creaminess", perhaps due to gonadal development (P. Dinnel, WWU, pers. comm.; Parker and Reid, unpublished manuscript). The latter authors indicated that the problem occurred in the summer, when gondal tissues were maturing.

We have noted that varnish clams kept in seawater tables will quickly purge sand from within the mantle cavity and gut, increasing palatability. However, if left for more than a few days, the clams begin processing sand from the tank (which they had purged only days before), and were once again "gritty", decreasing their appeal. This was considered a problem during test marketing in 1998 (R. Webb, pers. comm.). Feeding behaviours and recycling of sediment in tanks will have to be considered when assessing depuration of varnish clams. The high incidence of commensal pea crabs in varnish clams could also decrease market appeal, although they were considered a "value-added" product in oyster stews on the east coast in the 1700's (MacKenzie 1996).

Another problem with varnish clams may be "green feed". We were contacted by a gentleman who collected varnish clams for chowder, which he prepared by shucking the clams fresh from their shells, without steaming them first. His complaint was that the clams he had collected the previous day were stained black when shucked. In the process of shucking them, he had cut through the body mass, exposing the digestive gland, which was dark green ("black") with accumulated chlorophyll. The incident coincided with the first heavy phytoplankton blooms of the season.

Shelf-life, or the ability to remain alive while in transport and/or storage, appears to be considerably longer than for Manila and littleneck clams. We have noted very little mortality in varnish clam samples stored in plastic bags under refrigeration, where Manila and littleneck clams will begin to gape and die after only a few days. Yates (1999) reported complete mortality of Manila and littleneck clams after 3 weeks of refrigerated storage. Varnish clams held under the same conditions did not gape even after 4 weeks, and quickly opened and extended siphons and feet when placed in seawater.

Gains in shelf life may be offset by losses due to shell breakage during transport. The relatively soft, thin shells of varnish clams preclude the simple bagging and mass movement currently practiced with hardshell clams.

RESULTS OF PHASE 0 ASSESSMENT

The initial phase of Perry *et al.*'s (1999) framework for providing scientific advice for the management of new and developing fisheries, termed "phase 0", requires synthesis of available biological and fisheries information on the target (and similar) species, leading to formulation of potential management strategies. Biological and ecological information from this study are summarized in Table 6.

Obvious gaps in biological information include age and growth, reproduction (size and age at maturity, season, fecundity), early life history (larval period duration, dispersal) and recruitment. Ecological interactions between varnish clams and associated species have not been determined, although anecdotal information and concerns regarding potential competitive interactions with Manila clams, particularly in culture situations, have been expressed.

DISCUSSION

Distribution

The geographic distribution of varnish clams is still expanding, as their relatively recent discovery in Barkley Sound and continued southward dispersal in Puget Sound attest. Manila clams underwent a similar pattern of dispersal from their initial introduction in Ladysmith Harbour (Bourne 1982). Manila clams have not become well established in Johnstone and Queen Charlotte Straits (Bourne *et al*. 1994; Bourne and Heritage 1997; Heritage *et al*. 1998), and studies are required to determine whether varnish clams are expanding northward from Georgia Strait. Manila clams spread northward up the west coast of Vancouver Island, and this is believed to be the source of populations established in the Central Coast (Bourne 1982). Given the similarities in dispersal to date, varnish clams can be expected to expand northward, and may eventually become established in the Central Coast.

Whether the southern distribution of varnish clams in Oregon is a result of expansion from Georgia Strait or an independent introduction is unknown. Information on the existence and structure of varnish clam populations on the outer coast of Washington State (Willapa Bay or Grays Harbour) may provide clues to the relationship between northern and southern populations.

Competition

Concern has been expressed, both by clam culturists and fishers, that establishment of large populations of varnish clams will have a negative impact on Manila clam productivity. To date, these contentions have consisted of observation of beaches from which Manila clams are harvested, effectively reducing population levels of one of the alleged competitors. To our knowledge, there is no experimental data to provide scientifically valid information on the ecological relationships of varnish clams within the intertidal clam community.

In established systems, feeding ecology is an important factor in reducing competition in closely related species. Reid and Reid (1969) demonstrated that alternative feeding processes were important in allowing co-existence of eight congeneric species of *Macoma*, and alternative modes of feeding (*i.e.*, pedal feeding) have been linked to the success of the invasive freshwater clam *Corbicula fluminea* (Way *et al*. 1990; Reid *et al*. 1992). Parker and Reid (unpublished manuscript) proposed that supplementary pedal feeding contributed to the ability of varnish clams to inhabit greater tidal elevations.

Seapy and Kitting (1978) noted that *N. nuttalli*'s ability to retreat deeper in substrate allows this species to avoid desiccation stress. Utilization of areas of freshwater runoff or seepage, as well as the ability to live deep in the substrate could explain *N. obscurata*'s distribution in the upper intertidal zone.

Peterson (1977) indicated that competition for space may be the most important factor determining temporal and spatial organization of soft-bottom macrobenthic communities, likely keeping overall densities low enough for food to not be limiting. Although spatial competition likely occurs for the two-dimensional sediment-water interface, interstitial spaces between even tightly-packed organisms will still allow sufficient space for siphons of deep-living bivalves to access the water column. Competition would be most intense between species with the same spatial requirements, *i.e.*, those which occupy the same depths in the substrate. Peterson and Andre (1980) showed that growth of *N. nuttalli* was reduced ~80% when they were confined with deep-dwelling horse clams (*Tresus nuttalli*) and California butterclams (*Saxidomus nuttalli*), while growth was unaffected by the presence of shallow-dwelling littleneck clams. Spatial competition reduced growth rates in *Nuttallia* in the presence of dead shells of *Tresus* and *Saxidomus* placed in normal living positions. Conversely, growth of littleneck clams was unaffected by presence of any of the deep-dwelling species. Similarly, Urban (1994) demonstrated that utilization of different sediment types and burrowing depths allowed coexistence of six species of filter-feeding sessile bivalves in a single bay in Chile

Kamermans *et al*. (1992) demonstrated that interspecific competition between the deposit-feeding *Macoma balthica* and the filter-feeding *Cerastoderma edule* was weak or non-existent. Intraspecific competition caused decreased growth at high densities of *M. balthica*, but growth of *C. edule* was density-independent. They concluded that interspecific competition did not occur, and that intraspecific competition could be more readily expected in deposit feeding species than in filter feeders. If this holds true for the Manila/varnish clam interaction, one might expect that varnish clams could not out-compete Manila clams in an unperturbed system.

Varnish clams live deeper in the substrate than Manila or littleneck clams, thus reducing competition for space. They utilize different modes of feeding (deposit and pedal feeding) in addition to suspension feeding, which reduces competition for resources. High varnish clam abundance is observed in portions of the beach not well utilized by Manila clams – higher intertidal zone and areas of freshwater runoff and unstable substrates. On beaches which have abundant Manila clam populations, varnish clams are restricted to marginal habitats, although some overlap in distribution is possible due to depth distribution within the substrate. On beaches where Manila clams are selectively removed (*i.e.*, commercially harvested beaches and aquaculture tenures), varnish clams could expand their distribution in the relative absence of a competitor.

Thus, the competition question does not appear to be one of varnish clams displacing Manila clams in an unperturbed system, but whether Manila clam production from a harvested population is decreased when varnish clams increase in abundance in portions of the beach that had formerly been inhabited by Manilas.

Arguments that recently introduced varnish clams might have an impact on historically introduced Manila clams hold no ecological or moral high ground; they express concern that the more economically valuable species might be affected by the presence of the invader. Whether such competitive relationships even exist has yet to be proven, nor has the economic potential of the invading species been completely explored.

Fishery Potential

Fishery potential of varnish clams will be determined primarily by industry. This has been the case in the past when exotic species have developed commercial fishery value (Manila clams) and when valuable commercial species have failed to develop after introduction into British Columbia (eastern softshell clams). Manila clams arrived in the 1930s, and by the 1980s were the preferred species of intertidal clam fisheries in B.C. Eastern softshell clams arrived near the turn of the century, and are found throughout coastal B.C. (Quayle and Bourne 1972; Bourne and Cawdell 1992; Bourne *et al*. 1994; Bourne and Heritage 1997; Heritage *et al*. 1998) and in the Queen Charlotte Islands (Gillespie and Bourne 1998). Despite their commercial value on the east coast of North America, a commercial fishery has not developed in B.C., possibly due to the sparseness of the populations, the costs of harvesting and processing, or a combination of these and other factors (Gillespie and Bourne, in press).

Fishery potential of varnish clams will be determined primarily by economic viability, which depends on several factors:

- Does a market exist for the species, or can one be created?
- Is the species available in sufficient abundance to supply a market?
- Is the species productive enough to maintain abundance under harvest pressure?
- Is the market price sufficient to make commercial harvest attractive?
- Are market prices and productivity sufficient to offset the costs of water and product quality monitoring, assessment and management of the fishery?

Preliminary market testing was favourable, indicating that a market is either currently available, or could be established. Current population levels on commercial beaches and leased foreshore in British Columbia are sufficient to support a fishery, but the productive capacity of varnish clam populations under harvest pressure is unknown.

Limited information is available regarding market price, which will fluctuate with supply and demand of both varnish clams and competing products. The effect of introducing another product into the competitive steamer market on prices for all of these species is uncertain. Ideally, varnish clams could command Manila prices, and become established as a high quality steamer product, but it is also possible that they may be relegated to the role of a relatively inexpensive Manila substitute, similar to littleneck clams. In the latter case, it is possible that prices for Manila clams might be negatively affected.

Management Considerations

Development of management plans for varnish clams of management objectives that reflect the value and intended usage of the species. The first decision facing DFO is whether varnish clams represent an unwanted invader or a potential commercial resource. In the first case, the management objective would simply be to reduce varnish clam abundance to a level that minimizes impact of the species on production of more economically valued species. There is currently no DFO policy to support such an objective and reduction campaigns directed at varnish clam populations on beaches that support populations of other harvestable species are unjustified at this time.

In the second case, the rational development of a varnish clam fishery requires conservation goals, at a minimum similar to those currently applied to the fishery for Manila clams, a species that experienced a similar accidental introduction, and that has become the primary target of clam fisheries in B.C. The management framework for Manila clams in B.C., as outlined in Gillespie and Bond (1997), included:

- A minimum size limit of 38 mm TL;
- Area licencing to distribute effort (this was augmented by licence limitation in 1998);
- Establishment of historic production levels, which can be used as harvest targets, pending information that might lead managers to believe that historic levels might not be met (loss of productive beds to faecal contamination or loss of opportunity due to PSP closure); and
- In-season monitoring as harvest targets are approached .

Development of similar tactics for varnish clams could be established relatively quickly, except for development of a biologically-based size limit, which would require exploration of reproductive and growth characteristics of varnish clams, and establishment of production histories. In the short term, exploration of market potential, varnish clam biology, population dynamics and production could be explored through experimental harvests under scientific permit.

Before a commercial fishery can be considered, the basic information is required to assess the effectiveness of potential management strategies, which might include one or more of size limits, sex restrictions, total allowable catch (TAC)/quota regulation, or effort limitation. The collection of this information represents phase 1 of fishery development in the framework of Perry *et al*. (1999). The sex of clams cannot be determined externally, thus, sex restrictions are not a feasible management tactic. Other potential strategies and their information requirements are discussed below.

Size Limits

Size limits have been used in commercial fisheries for other clam species to prevent overharvest of the reproductive portion of the population. Therefore, it is attractive to utilize a minimum size limit as a management tactic to prevent recruitment overfishing of varnish clam populations. Minimum size limits for littleneck (38 mm TL), butter (63 mm TL) and razor clams (90 mm TL) were determined following research to ascertain size at first maturity for each species (Bourne 1987). The size limit for littlenecks was applied to Manila clams when commercial fisheries began landing them in the 1940's. Fortunately, size at first maturity of Manila clams was smaller than for littleneck clams, and the use of 38 mm TL as the minimum size was able to effectively address the management objective.

Size at maturity for varnish clams is not known. Maximum size of varnish clams, as currently understood (~68 mm TL), is smaller than that of Manila and littleneck clams (75 mm TL) (Gillespie and Kronlund 1999). Length frequencies of varnish clams in B.C. (*e.g.*, Figure 7) and in Puget Sound (Yates 1999) indicate that a relatively small proportion of the population is >38 mm TL. Thus, application of a minimum size limit of 38 mm TL until size at maturity is determined would be precautionary. However, larger clams may not be as palatable as small clams, at least during the season in which the gonads are well developed (P. Dinnel, WWU, pers. comm.). Further research is required to evaluate the effectiveness of a size limit relative to life history traits of the species, to maximize production without impacting reproductive potential.

One negative consideration in the use of a size limit is the fate of animals discarded during harvest. Varnish clams will quickly rebury if left on the substrate surface, although these observations are limited to summer surveys, and effective reburying at low temperatures is unknown. Of more concern are clams broken during harvest. These clams will not survive, and discards lost due to breakage will not be reflected in landing statistics. Size limits are only effective when mortality of released clams is low.

TAC/Quota Regulation

Quotas are used in B.C. intertidal clam fisheries when a specific beach has been allocated to a user group, primarily for depuration fisheries or pilot opportunities for First Nations (Gillespie and Bond 1997). Total Allowable Catches (TAC's) are calculated from survey estimates using arbitrary harvest rates, which are currently being evaluated experimentally.

TAC's could be used for varnish clam fisheries where the same allocation and survey frameworks can be applied. Qutoas are not practical for large-scale fisheries exploiting a number of beaches in an area where survey estimates are not available.

Harvest targets based on historic production are used in conjunction with in-season monitoring to manage Manila clam fisheries, and it is possible that a similar framework could be developed for varnish clams once a harvest history is established. Other targets based on theoretical harvest rates have considerably more stringent data requirements.

Interaction with Existing Intertidal Clam Fisheries

Varnish clams are found relatively deep in the substrate, often under Manila clams. Therefore, varnish clam harvests will have a direct impact on Manila clam populations, whether as removals during concurrent harvests, or through impacts on clams that have been disturbed and discarded. Varnish clam fisheries should be undertaken in conjunction with Manila harvests, except under special circumstances, where they are found in the absence of Manila clams. Additional opportunities to harvest varnish clams after conservation thresholds have been exceeded are not recommended.

Intertidal clam fisheries in British Columbia have undergone development through a joint federal/provincial program known as clam reform. A major undertaking in this process has been to institute licence limitation, which was enacted in 1998. Licence limitation was a management tactic designed to reduce effort levels in clam fisheries, allowing for more opportunities for fewer licenced diggers, greater economic benefits to participants, and a slowing of harvest rates to allow better control of the fishery. Therefore, it is desirable to view the varnish clam as an opportunity to diversify the existing clam fishery, with the benefits going to the existing fishers, rather than a new fishery to be licenced, assessed and managed independently.

Assessment Tools

Assessment of varnish clam populations in B.C. will depend on the management tactic chosen. Passive management utilizing minimum size limits require only development of biologically-based minimum size limits and monitoring of index populations to ensure that conservation goals are adequately addressed. Quantitative assessment of target or threshold harvest rates require landings and detailed assessment surveys from individual index beaches. TAC's require annual assessment surveys and documentation of landings from individual beaches. Regardless of the management tactic chosen, monitoring programs are required to quantify losses due to breakage post-harvest, and incidental mortality of clams not harvested, but disturbed or broken during harvest.

Existing protocols for intertidal clam surveys (Gillespie and Kronlund 1999) are adequate to develop quantitative estimates of varnish clam populations, provided that quadrats are dug to a depth that includes all available varnish clams. The sampling intensity of 30 quadrats/ha recommended for Manila clam surveys should be re-evaluated (*fide* Kronlund *et al*. 1998). Because surveys will likely be for Manila clams as well as varnish clams, a 0.25 m^2 quadrat is likely appropriate, provided it is dug at least 40 cm deep in the substrate.

More problematic is the ability to age varnish clams accurately. No studies have been carried out that provide repeatable criteria for ageing, making assessment of recruitment or age-structured analyses of varnish clam populations impossible. Without a maximum expected age of varnish clams in B.C., or some independent estimate of natural mortality rates, even the simplest biologically based harvest rates that relate fishing mortality to natural mortality ($F = M$, or $F = xMB_0$) are impossible.

The issue of competition, exclusion or decreased production of more economically important species, can only be addressed experimentally, or through serial surveys of areas with and without varnish clams. We advocate use of the methods of Peterson and Andre (1980) to evaluate species interactions in controlled experiments. Larger scale experimental approaches will be required to assess interactions of varnish clams and other species in perturbed (*i.e.*, selectively harvested) systems.

RECOMMENDATIONS

The following recommendations are presented:

1. **Varnish clams should be considered as a potential commercial and recreational resource, not an unwanted invader, and managed accordingly.** They have had relatively favourable responses in both commercial markets and with some recreational harvesters.
2. **Managers should consider incorporation of varnish clams into existing intertidal clam fisheries, rather than development of a new fishery to be assessed and managed independently.** Varnish and Manila clams occur on the same beaches, and in many cases harvests would require displacement of Manilas while digging for varnishes. Commercial clam fisheries in B.C. have recently gone through a painful period of re-evaluation and management reform, including licence limitation, with the stated objectives of reduced participation, increased value of the fishery to individual harvesters, and increased stewardship and responsibility for the resource resting with harvesters and community management boards. Development of an independent clam fishery for a new species would undermine these objectives, and create conflict between user groups.
3. **Except for those opportunities that allow harvest of varnish clams in the absence of Manila clams, no additional harvests of varnish clams should be considered at this time once Manila clam conservation thresholds have been achieved.** Varnish clam harvests will, in some cases, have detrimental impacts on Manila clam populations, as they live in the same areas, but deeper in the substrate. Management objectives may change as more information is gathered on ecological relationships and relative economic benefits of each species.
4. **Varnish clams may represent a possibility for diversification of clam culture operations, utilizing naturally-occurring varnish clams as an additional product.** Increased understanding of relationships between varnish and Manila clam populations on leased foreshore may lead to strategies that maximize production of the species aggregate, rather than attempting to minimize the impact of varnish clams on Manila clam production.
5. **Research to determine the ecological relationships of varnish clams and other intertidal bivalves should have a high priority.** Fishers and aquaculturists have expressed concerns regarding the effect varnish clams may have on other clam populations, particularly economically important Manila clams. The ecological role and competitive status of varnish clams in B.C. requires experimental testing or careful comparison of data from beaches that support varnish clam populations and beaches that have not yet been colonized. We suggest that decisions related to management of varnish clams be based on scientifically valid data and conclusions, not unsupported opinion.
6. **Research to determine biological characteristics and population dynamics of varnish clams is required before a commercial fishery is developed.** Potential management frameworks for clam fisheries cannot be applied and evaluated without

information on age, growth, reproduction, early life history, recruitment and stock productivity.

ACKNOWLEDGEMENTS

We thank Bill Austin (Khoyatan Marine Laboratories, Cowichan Bay), Neil Bourne (Pacific Biological Station, Nanaimo), Paul Dinnel (Western Washington University, Bellingham), Glen Jamieson (Pacific Biological Station), Phil Lambert (Royal British Columbia Museum, Victoria), Robert G.B. Reid (University of Victoria) and Paul Valentich Scott (Santa Barbara Museum of Natural History) for sharing information related to varnish clam distribution, biology and ecology. We also thank Neil Bourne, Paul Dinnel and Randy Webb (DFO Fish Management Branch, Parksville) for their reviews of the manuscript.

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Table 1. A list of exotic molluscs found in British Columbia.

Species	Native Distribution	Comments
Gastropods		
Clanculus ater (Trochidae) – Topsnail	NW Pacific	Historic record from Queen Charlotte Sound; status unknown
Cecina manchurica (Pomatiopsidae) – Manchurian cecina	NW Pacific	Reported from Boundary Bay, invaded with Pacific oysters
Batillaria attramentaria (Batillariidae) - Japanese false cerith	NW Pacific	Established; abundant mudflat snail invaded with Pacific oysters
Sabia conica (Hipponicidae) – Hoofsnail	NW Pacific	Historic records from Queen Charlotte Sound and Vancouver Island; status unknown
Crepidula convexa (Calyptraeidae) – Convex slippersnail	NW Atlantic	Invaded with Atlantic oysters, reported from Boundary Bay
Ocinebrina inornata (Muricidae) - Japanese rocksnail	NW Pacific	Invaded with Pacific oyster seed, locally common
Urosalpinx cinerea (Muricidae) – Atlantic oyster drill	NW Atlantic	Invaded with Atlantic oyster seed, established in Boundary Bay
Nassarius obsoletus (Nassariidae) – eastern mudsnail	NW Atlantic	Invaded with Atlantic oyster seed, established in Boundary Bay
Nassarius fraterculus (Nassariidae) – Japanese nassa	NW Pacific	Boundary Bay, invaded with Pacific oysters
Myosotella myosotis (Melampodidae) – European ovatella	NE Atlantic	Boundary Bay, invaded with Atlantic oysters
Bivalves		
Mytilus galloprovincialis (Mytilidae) - Mediterranean mussel	Mediterranean	Introduced in Georgia Strait, possibly arrived as fouling organism on ships
Musculista senhousia (Mytilidae) – Green mussel	NW Pacific	Invaded Puget Sound with Pacific oysters, established in Georgia Strait
Patenopecten yessoensis (Pectinidae) - Japanese sea scallop	NW Pacific	Cultured on-bottom in Georgia Strait, apparently not established
Crassostrea gigas (Ostreidae) – Pacific oyster	NW Pacific	Introduced throughout B.C., established in southern B.C.
Crassostrea virginica (Ostreidae) – Atlantic oyster	NW Atlantic	Introduced to many localities in Georgia Strait, established in Boundary Bay
Ostrea edulis (Ostreidae) – European flat oyster	NE Atlantic	Reported from Barkley Sound; status undetermined
Neotrapezium liratum (Trapeziidae) – Quadrate trapezium	NW Pacific	Historic record from Ladysmith, established in Boundary Bay
Venerupis philippinarum (Veneridae) - Manila clam	NW Pacific	Invaded with Pacific oysters, established in south and central B.C.
Mercenaria mercenaria (Veneridae) - Northern quahog	NW Atlantic	Believed to be established only in Alamitos Bay, but also reported from Boundary Bay, intentional release
Ptericolaria pholadiformis (Petricolidae) – False angelwing	NW Atlantic	Reported from Boundary Bay, believed to be introduced with Atlantic oysters
Mya arenaria (Myidae) – Eastern softshell clam	NW Atlantic	Invaded San Francisco Bay with Atlantic Oyster seed, spread north quickly, established throughout B.C.
Lyrodus takanoshimensis (Teredinidae) - Shipworm	NW Pacific	Invaded with Pacific oysters in wooden shipping crates,
Teredo navalis (Teredinidae) – Naval shipworm	NE Atlantic (?)	Historic records in Pendrell Sound

Table 2. Mean density of Manila, littleneck and varnish clams (clams/m^2) by elevation from Savary Island, May 1996.

Elevation	No. of Quadrats	Varnish		Manila		Littleneck	
		Mean	SE	Mean	SE	Mean	SE
Upper	12	130.32	218.57	179.00	131.87	32.00	27.40
Middle	12	40.68	70.18	193.68	323.55	23.32	24.17
Lower	12	50.00	62.28	199.68	201.71	38.68	28.86

Table 3. Estimated size at age (mm TL) for varnish clams from Fidalgo Bay, Puget Sound, and Savary Island, based on interpretation of length frequency data.

Age Class	Sample				
	Fidalgo 1999	Savary 1999	Savary 1998	Savary 1997	Savary 1996
0	-	11	-	-	10
1	17	22	16	17	19
2	22	27	22	26	-
3	33	32	30	31	-
4	43	-	37	-	-
5	53	-	-	46	-
6	-	-	-	-	-

Table 4. Incidence of pea crabs, *Pinnixia faba*, in varnish clams, *Nuttallia obscurata*, from Departure Bay, B.C., December 1998-September 1999.

Month	No. of quadrats	No. of clams	Incidence	SE
Dec 1998	1	208	0.75	0.00
Jan 1999	3	224	0.42	0.03
Feb 1999	3	227	0.24	0.24
Mar 1999	3	195	0.43	0.34
Apr 1999	3	189	0.55	0.09
May 1999	4	332	0.33	0.19
Jun 1999	3	287	0.24	0.07
Jul 1999	3	257	0.21	0.10
Aug 1999	3	274	0.22	0.05
Sep 1999	2	272	0.17	0.10

Table 5. Location of moonsnail (*Euspira lewisii*) drill holes in clam shells.

Position of drill site	% shells drilled		
	Bernard (1967) (primarily butter and littleneck clams)	Littleneck clams (Rathtrevor Beach)	Varnish clams (Shark Spit)
Left valve	61	72	41
Right valve	39	28	59
Region of umbo	92	100	73
Away from umbo	8	0	27
Partially drilled	7	-	-

Table 6. Summary of biological and ecological information for varnish clams in British Columbia.

	Varnish clam
Scientific name	*Nuttallia obscurata*
Max. size	64 mm TL
Max. weight	45.1 g
Max age	Unknown
Size at maturity	Unknown
Age at maturity	Unknown
Feeding method	Suspension feeding planktovore, deposit feeding omnivore
Reproductive method	Synchronous broadcast spawner
Fecundity	Unknown
Spawning season	Unknown, possibly late winter with spring settlement
Larvae	Pelagic
Larval period	Unknown
Size at settlement	(?) 0.20-0.27 mm TL
Natural mortality rate	Unknown
Recruitment pattern	Unknown
Geographic distribution	Georgia Strait, northern Puget Sound, west coast Vancouver Island, estuaries on Oregon coast; currently expanding
Habitat	Sand/mud/mixed substrates, euryhaline
Tidal elevation	Upper to middle third of intertidal
Substrate depth	On surface to at least 30 cm
Primary associates	Manila, littleneck, softshell, *Macoma* clams and cockles
Symbionts/parasites	Pea crabs (symbiotic)
Predators	Moonsnails, gulls, crows, shorebirds, (?) crabs

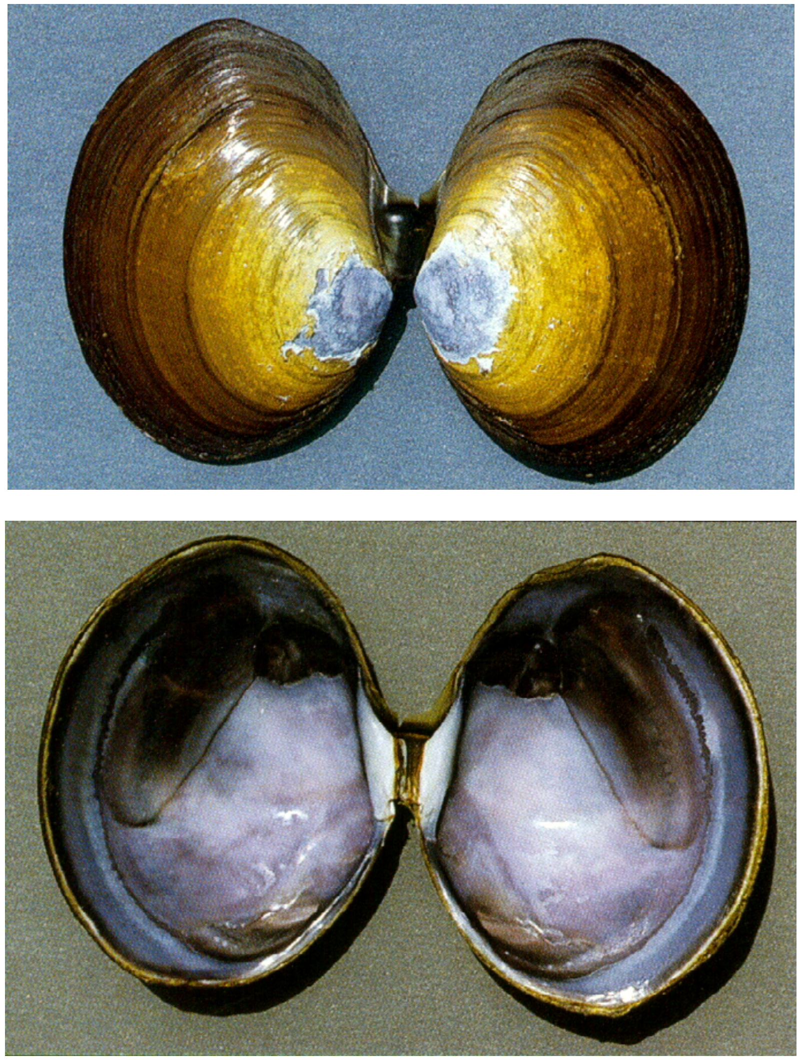


Figure 1. The varnish clam, *Nuttallia obscurata*.

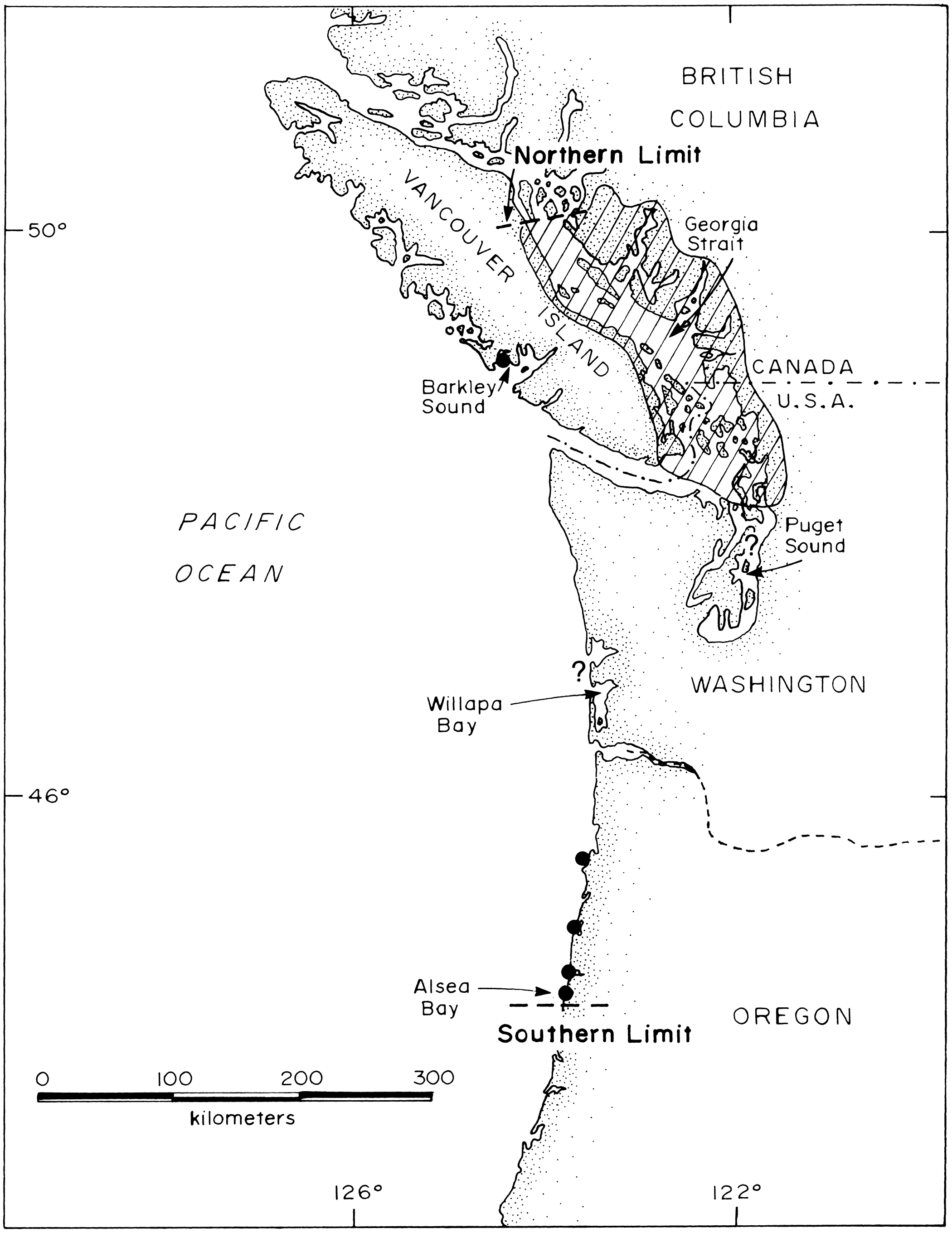


Figure 2. Distribution of the varnish clam, *Nuttallia obscurata*, in North America.

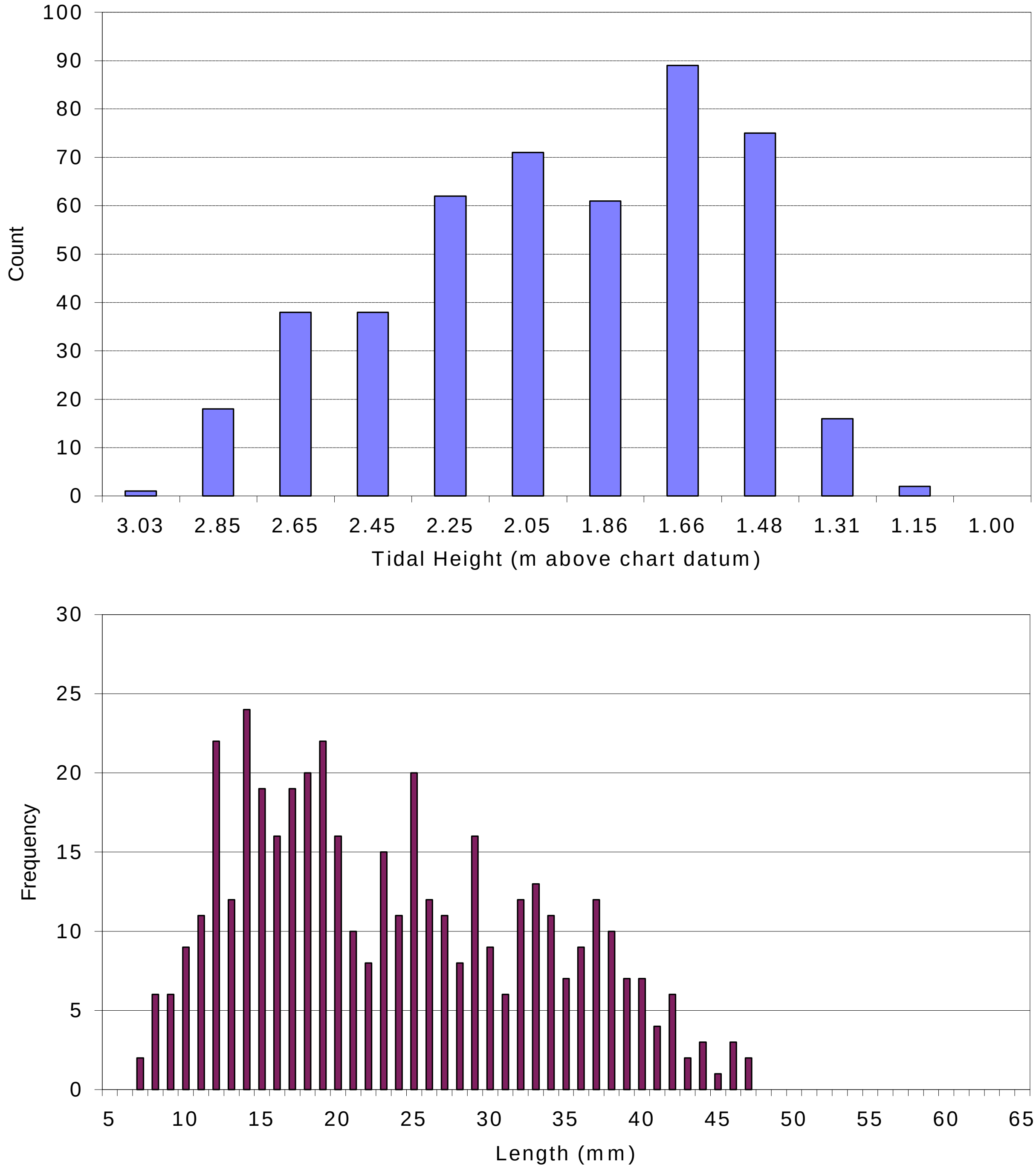


Figure 3. Density (clams/0.05 m^2 quadrat) of varnish clams by tidal elevation (upper panel) and length frequency distribution of sampled varnish clams (lower panel) from Departure Bay, B.C., July 1997.

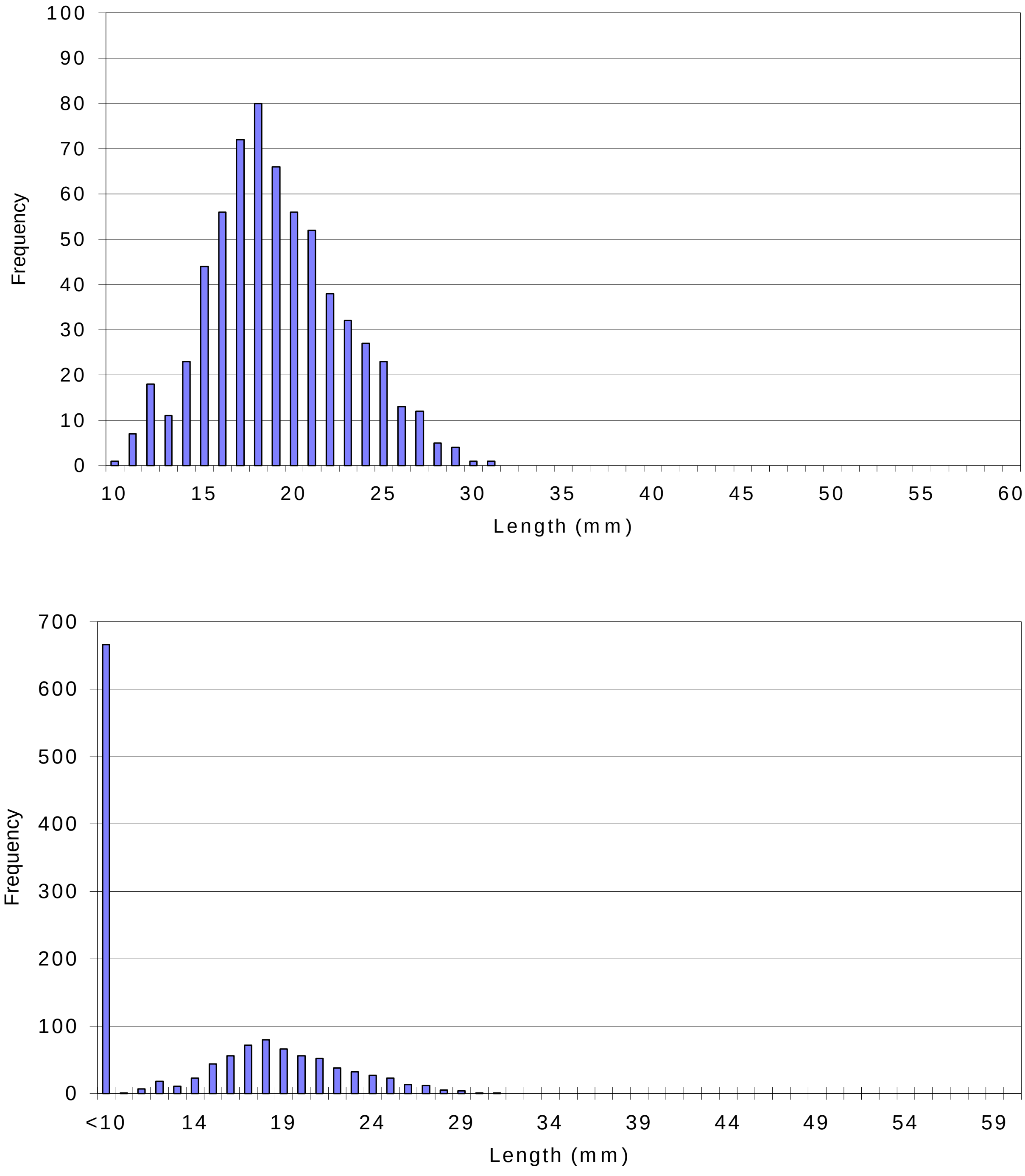


Figure 4. Length frequency distribution of varnish clams from Savary Island, May 1996. The upper panel includes only clams greater than 10 mm TL, the lower panel includes clams obtained from screened samples as a single size class.

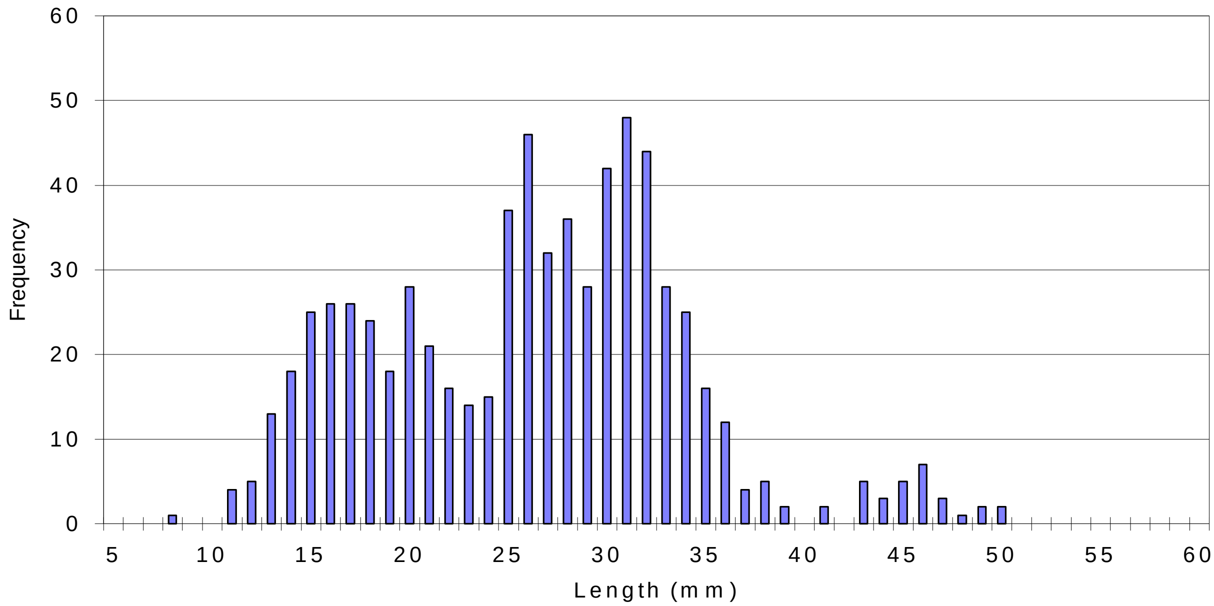


Figure 5. Length frequency distribution of varnish clams from Savary Island, April 1997.

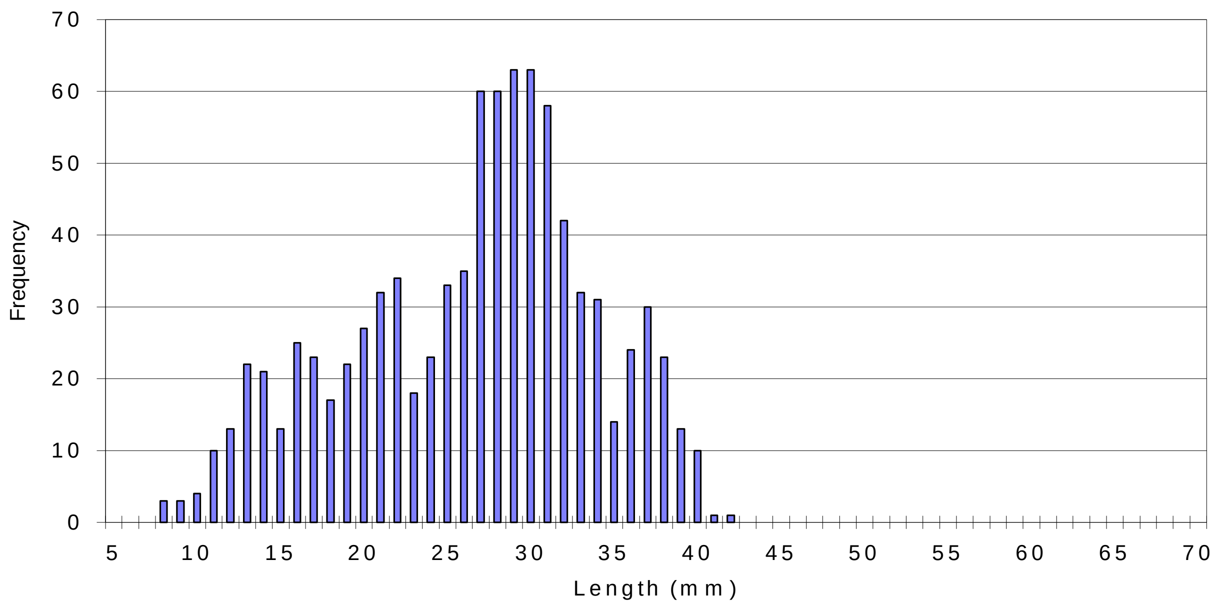


Figure 6. Length frequency distribution of varnish clams from Savary Island, April 1998.

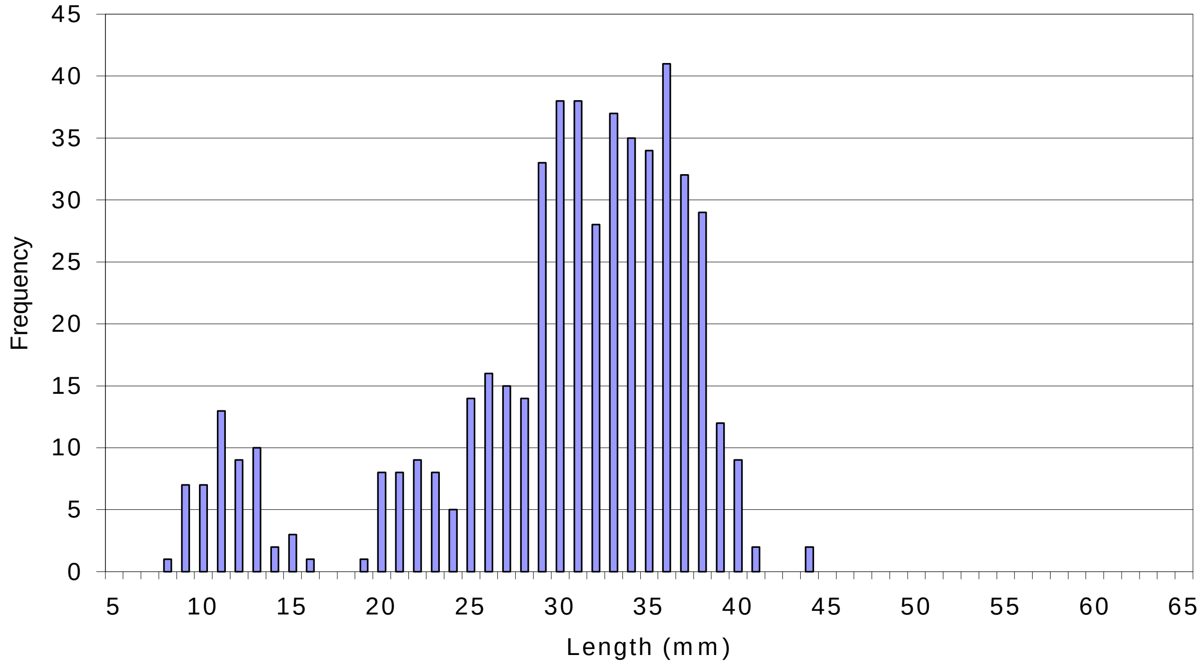


Figure 7. Length frequency distribution of varnish clams from Savary Island, April 1999.

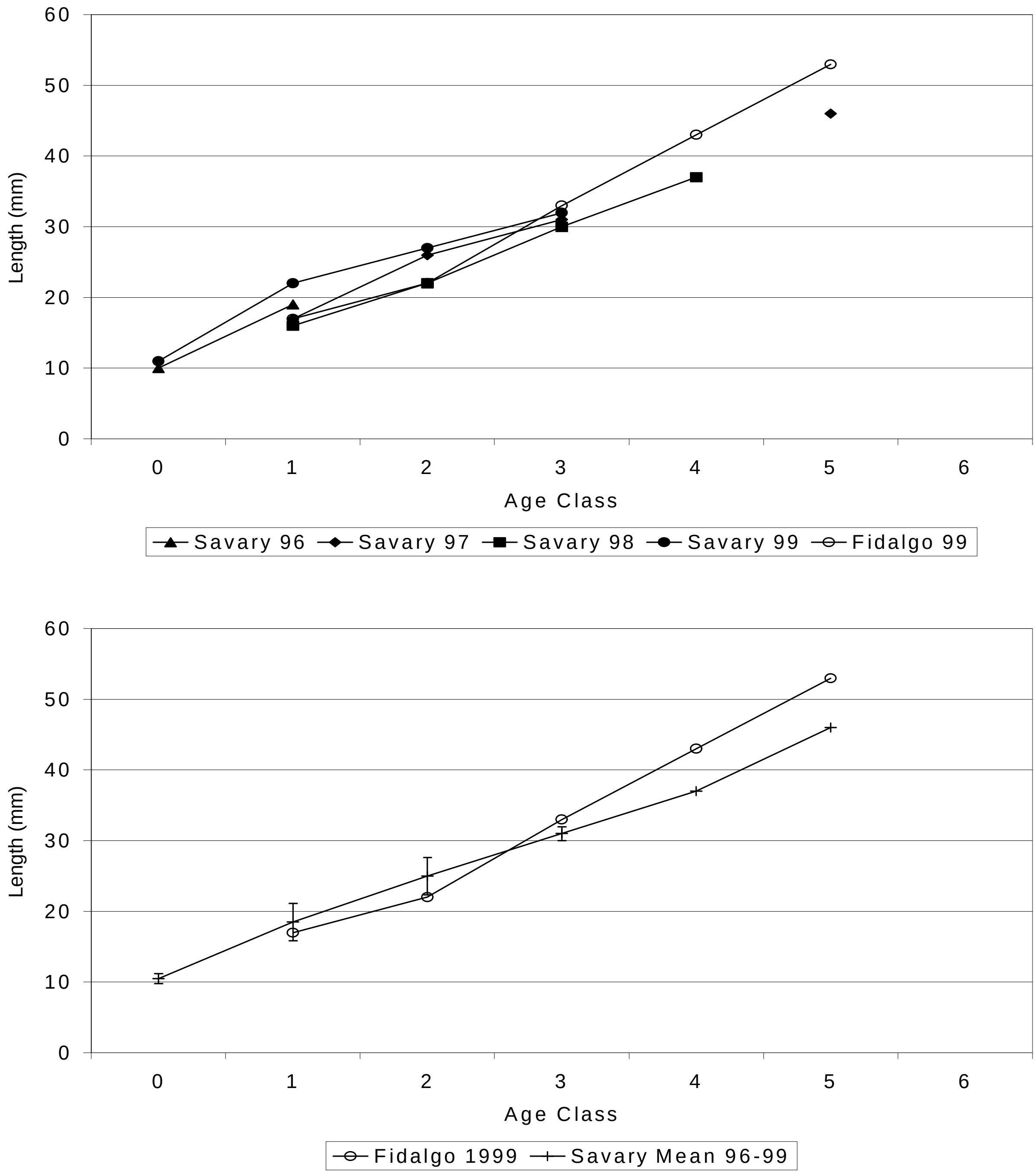
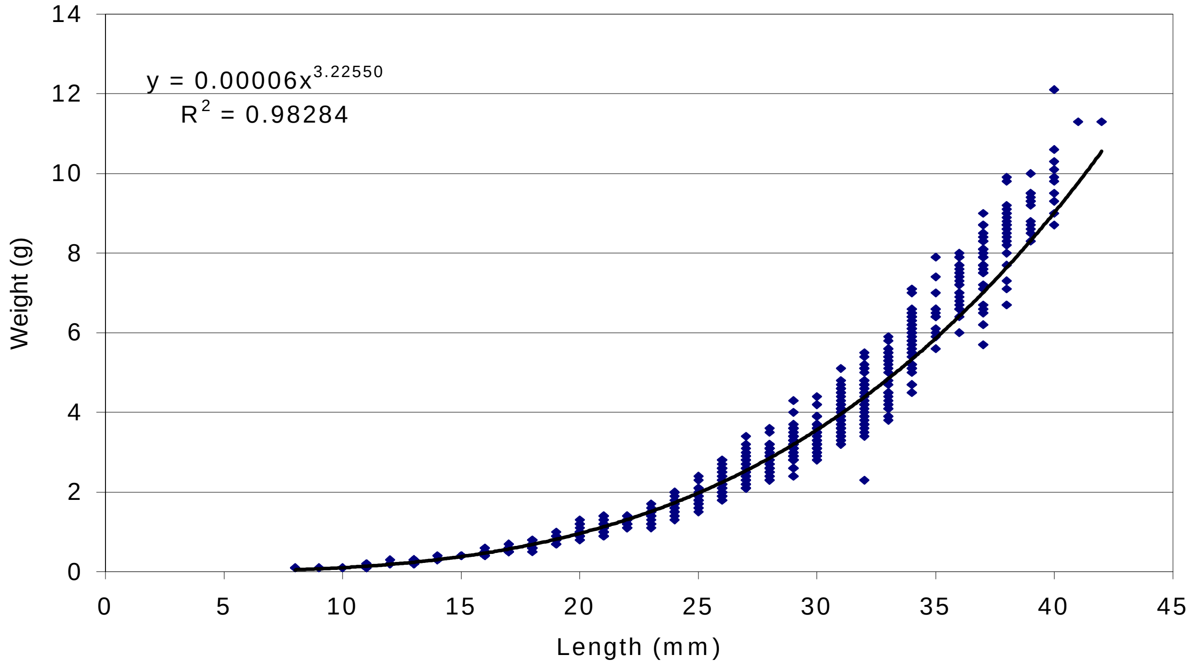


Figure 8. Length-at-age (mm) for varnish clams from Fidalgo Bay and Savary Island, estimated from length frequencies. The lower panel compares Fidalgo data with mean length-at-age from Savary 1996-99. Error bars are +/- 1SE.



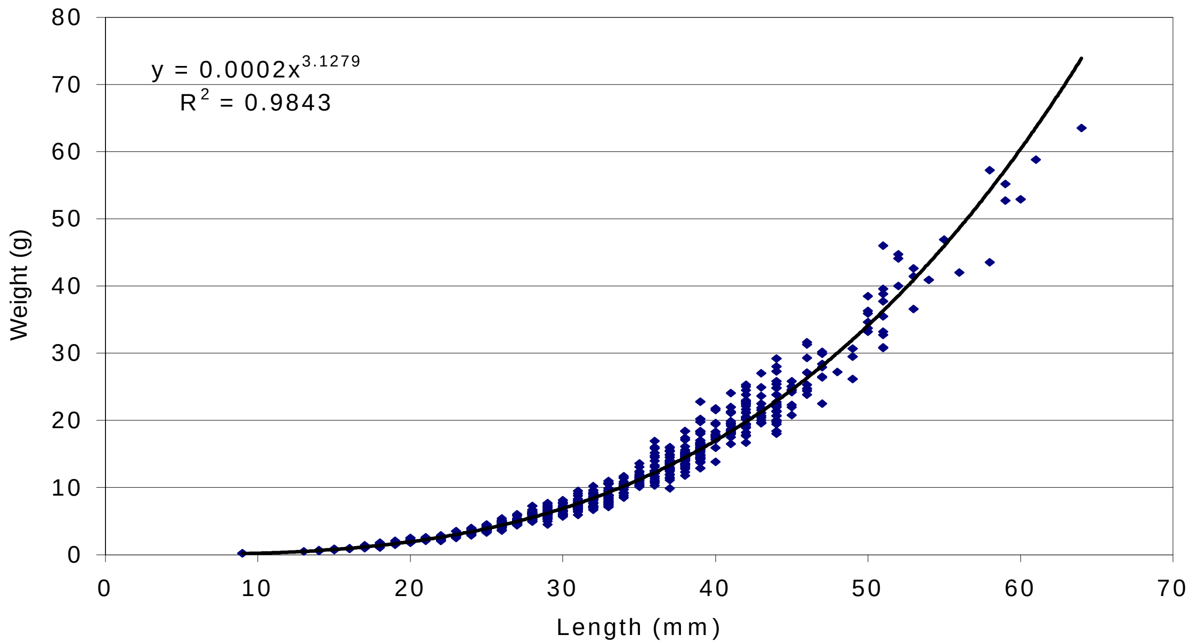


Figure 9. Length-weight relationships for varnish clams (upper panel) and Manila clams (lower panel) from Savary Island, April 1998. Total samples sizes are 880 and 674, respectively.

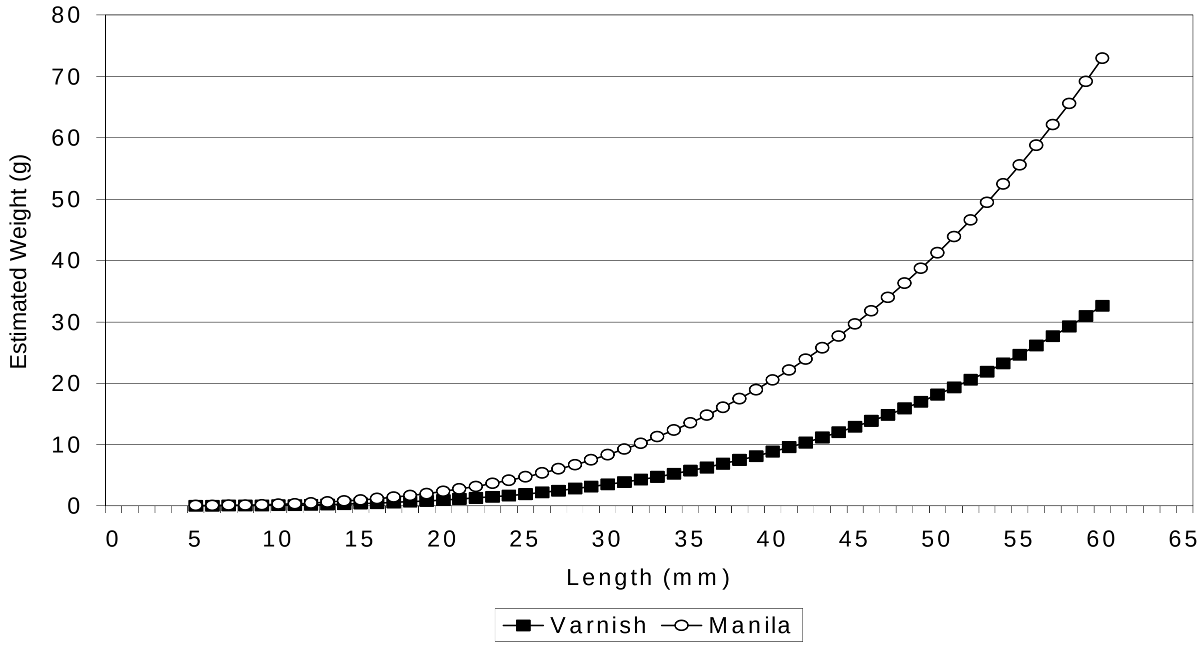


Figure 10. Theoretical length-weight relationships of varnish and Manila clams, based on the April 1998 Savary Island data.

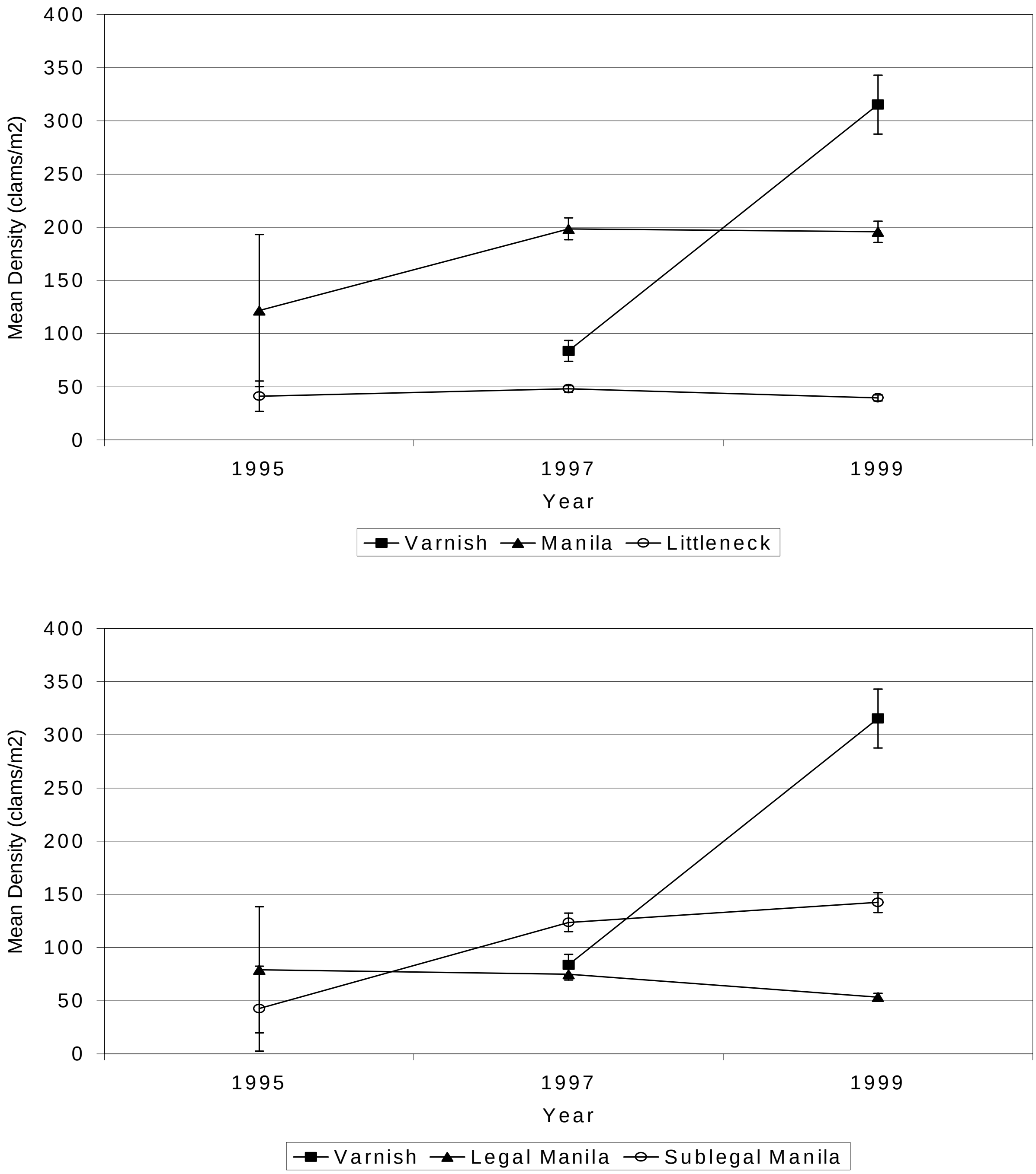


Figure 11. Mean densities of varnish, Manila and littleneck clams at Savary Island, 1995-99. Error bars are +/- 1 SE.

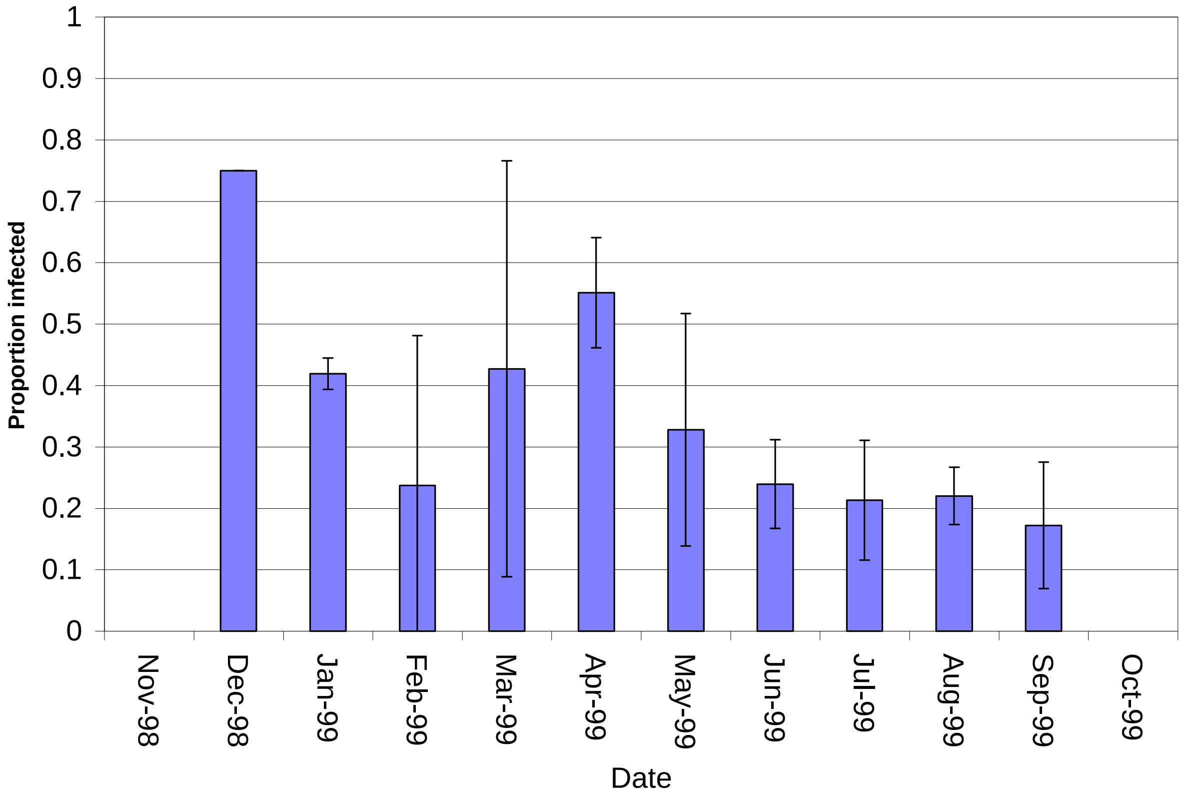


Figure 12. Incidence of pea crabs, *Pinnixia faba*, in varnish clams from Departure Bay, December 1998-September 1999. Error bars are +/- SE.