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A review of the biology and fisheries of the Goose Barnacle (*Pollicipes polymerus* Sowerby, 1833)

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Abstract

A review of the biology of goose barnacles (*Pollicipes polymerus* Sowerby, 1833) and a review of the fisheries of goose barnacles in British Columbia is presented, based on scientific literature, previous surveys and technical reports. Information shortfalls are identified, and recommendations for additional information requirements for stock assessments and management plans are given.

Résumé

Un examen de la biologie du pouce-pied (*Pollicipes polymerus* Sowerby, 1833) de même que de la pêche de cette espèce en Colombie-Britannique est présenté ; il est fondé sur les publications scientifiques, les relevés antérieurs et les rapports techniques. Les carences d'information sont précisées et des recommandations sont formulées relativement à d'autres besoins en matière d'information pour l'évaluation des stocks. Des plans de gestion sont aussi présentés.

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1. Introduction

The goose barnacle *Pollicipes polymerus* (Sowerby, 1833) has been commercially harvested in British Columbia since 1978, and is considered a traditional food by several coastal First Nations. Harvesters require a Z-6 licence for this fishery, the season is open year-round, and there is no limited entry. There has been a preliminary assessment and market feasibility study of goose barnacle stocks in British Columbia (Austin 1987), but there has not been a specific recommended or allocated quota. There is a building desire on the part of some active Z-6 licence holders to form a harvesters association to actively manage this fishery and to develop the stable markets for this high value product, with currently low landings.

Fisheries and Oceans Canada (DFO) had placed a moratorium on new invertebrate fisheries in the Pacific Region in 1992, as the department had lacked the resources to collect and analyze the biological information necessary to develop a sound management strategy. Since then, DFO and the British Columbia Ministry of Fisheries (formerly the Ministry of Agriculture, Fisheries and Food) proposed several new invertebrate stocks for potential exploitation, including the neon flying squid (*Ommastrephes bartrami*), Pacific milky Venus clam (*Compsomyax subdiaphana*), and the deepwater or grooved Tanner crab (*Chionoecetes tanneri*). In addition, octopus (*Octopus dofleini*), horse clams (*Tresus capax* and *Tresus nuttallii*), California mussels (*Mytilus californianus*) and goose barnacles (*Pollicipes polymerus*) were identified as high priorities for expansion from incidental fisheries to targeted fisheries.

A seafood diversification board was formed with representatives from DFO and the British Columbia Ministry of Fisheries. The mandate of the board was to develop the Pacific Region Policy for New and Developing Fisheries. This policy describes a phased precautionary approach, to ensure an orderly development of a sustainable, viable fishery. This paper was requested to ensure the management of the goose barnacle fishery is based on biologically sound principles, and follows a phased precautionary approach.

1.1 Plan for the Development of a Directed Fishery on Goose Barnacles

Within the Stock Assessment Division of DFO, a framework was developed for the provision of scientific advice for the management of new and developing invertebrate fisheries, including established fisheries whose expansion is limited due to a lack of information of the species distribution or abundance (Perry *et al.* 1998). This framework included three phases for the precautionary development of a fishery:

> <u>Phase 0:</u> Collection of all available information on the target species, and from similar species elsewhere, to provide a baseline with which to advise on the alternative management options and to identify areas where information is lacking;

Phase 1: Involves surveys and experimental fishing where the objective is the collection of data required to fill in the information gaps identified in the first phase and to explore the fishery potential.
Phase 2: Fishing for Commerce. A fishery is developed at the commercial level, while stocks are monitored and management strategies are evaluated.

This paper presents the Phase 0 review of known and derived information on the goose barnacle species (*Pollicipes polymerus*) found in British Columbia. It includes a review of goose barnacle distribution, life history and biology, population dynamics, abundance and a summary of goose barnacle fisheries in B.C.

1.2 Biological Objectives

The biological objective for a fishery on goose barnacles is to maintain a viable, healthy, and productive stock throughout their natural range in British Columbia. Rice et al. (1995) provided three basic biological objectives for the management of Pacific Region fish and invertebrate stocks. These provided the framework for the specific biological objectives for goose barnacles:

1. Ensure the population and subpopulations of goose barnacles along the B.C. coast do not become biologically threatened, as defined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), throughout their ecological range.
2. Ensure sufficient production and survival of progeny, after accounting for all sources of mortality (including all fisheries and natural mortality), to ensure sustainable reproduction throughout its ecological range.
3. Ensure that a fishery for goose barnacles does not violate the two previous objectives for other ecologically related species.

There is an underlying requirement to collect sufficient biological data in order to determine a safe (in terms of risk averse) level of harvest, as well as to be able detect changes in stock dynamics (from any cause) in time to prevent long-term decline or collapse of the stock due to over-exploitation.

2. Current Knowledge of *Pollicipes polymerus*

2.1 Biology and Life History

2.1.1 Background

The goose barnacle *(Pollicipes polymerus* Sowerby, 1833*)* (Subclass Cirripedia, Order Thoracica, Suborder Lepadomorpha, Family Scalpellidae, Subfamily Pollicipinae) is also known as the gooseneck barnacle or leaf barnacle. This species, previously named *Mitella polymerus*. *P. polymerus*, is a stalked or pedunculate barnacle, characterized by a pliable but muscular armoured stalk, the peduncle, with a strong attachment system, and a series of thick plates over the rest of the body, the capitulum (Fig 1).

There are three other species in the same genus, *P. pollicipes (=P. cornucopia)* found in the Atlantic Ocean, *P. elegans* found in the tropical Pacific, and *P. spinosus* found in New Zealand. These shore dwelling barnacles are typically found in physically rigorous environments with heavy surf action. There are other stalked barnacles which are typically found on stationary or slow moving floating objects in the open ocean, as well as species living on whales, jellyfish and other organisms. Some species live subtidally in shallow to deep water (Austin, *pers. comm.*).

2.1.2 Geographic Distribution

The goose barnacle ranges from Sakhalin Island in the Northwest Pacific, throughout the Aleutians, and down the west coast of North America to Cedros Island, Baja California Sur, Mexico (28°N) (Bernard 1988). It is also found sporadically as far south as Punta Santo Domingo, Mexico (26°N) (Cimberg 1981).

The commercial goose barnacle fishery has traditionally concentrated on the West Coast of Vancouver Island in Pacific Fishery Management Areas 23, 24, 25 and 26, with sporadic landings from the Central Coast and North Coast.

2.1.3 Habitat, Ecological Relationships, and Co-occurring Species

The rocky open exposed coast is the preferred habitat of goose barnacles, where they are typically very gregarious (Barnes and Reese 1960, Ricketts and Calvin 1968, Newman and Abbott 1980). Goose barnacles often occur in distinctive rosette-shaped aggregations (Hoffman 1989). These aggregations are typically tightly formed humped clusters 20-40 cm in diameter (Fig 2), with the large older individuals at the centre, surrounded by a gradation of smaller younger individuals at the periphery (Bernard 1988). On the West Coast of Vancouver Island, adult goose barnacles are found on various types of rock substrates, including basalt, coarse and medium grained quartz diorite, diorite, a metasiltstone and argillite (Austin 1987).

Goose barnacles can tolerate salinities down to 19 ppt. (Fyhn *et al* 1972) and water temperatures up to 20°C for several days at a time (Page 1983, Austin 1987). They are also well adapted to obtaining oxygen in air, consuming 3 to 5 times more oxygen in air than in water (Petersen *et al* 1974). However, oxygen may become a limiting factor during holding or shipping operations, as seen in differences in mortalities between in barnacles in current swept areas and those held in calm waters, and differences between packed and loose barnacles (Austin 1987).

In most of the wave-exposed areas, populations are concentrated in the midlittoral zone, but individuals may range from over a meter above the highest high water level down to the shallow subtidal (Austin 1987). In southern California, Barnes and Reese (1960) found the intertidal distribution of goose barnacles to be typically restricted to below the *Chthalmalus* spp. zone and the main belt of *Balanus glandula*. They were not found subtidally below abundant intertidal aggregations (Barnes and Reese 1960). They are usually the dominant organism in the upper two thirds of the intertidal zones of the open exposed rocky coasts of southern Alaska and British Columbia (Bernard 1988). On the west coast of Vancouver Island, goose barnacles are often found closely associated with, and attached to, California mussels (*Mytilus californianus*) and the acorn barnacle (*Semibalanus cariosus*) (Austin 1987).

In the lower midtidal, the purple starfish (*Pisaster ochraceus*) is often noted as a predator on goose barnacles (Feder 1959, Paine 1980, Austin 1987) as well as on mussels. However, only the upper distribution of the purple starfish coincides with the lower distribution of goose barnacles, so the incidence of predation is fairly low (Feder 1959, Paine 1980). Predatory snails (*Nucella spp.*) as well as gulls (*Larus glaucescens*) are major predators on goose barnacles (Meese 1993, Wootton 1994, Wootton 1997). Bernard (1988) listed potential predators on goose barnacles in order of significance: purple starfish (*Pisaster ochraceus*); muricid snails (*Nucella emarginata* and *N. lamellosa*) and small pagurid crabs. Bernard (1988) also found that several species of polychaetes were active predators on newly settled animals.

In the lower midtidal, goose barnacles often occur interspersed in dense aggregates with the California mussel, and the bay mussel (*Mytilus edulis*) to form the distinctive *Pollicipes-Mytilus* community (Barnes and Reese 1960, Hoffman 1989). There has been a number of extensive studies on the *Pollicipes-Mytilus* community and the effects of competition, predation and disturbance on succession in this community (Dayton 1971; Paine 1974, 1980; Paine and Levin 1981; Wootton 1992, 1993, 1997). A review of these studies could be the subject of an entire review paper. Only a very brief summary will be provided for this paper. Paine (1974) reported that on horizontal mid-intertidal surfaces, California mussels are the dominant organisms, effectively outcompeting or rendering the primary space unavailable to all other plant or animal species. However in near vertical surfaces or overhangs, goose barnacles are dominant, as California mussels cannot persist (Fig 3). In common areas, goose barnacles are capable of co-existing with California mussels for at least 6 years. Paine and Levin (1981) studied California mussel patch dynamics and the competitive interactions of goose barnacles in patch recovery. They showed that “catastrophic” disturbances of California mussel patches provided a unique invasion opportunity for goose barnacles, but goose barnacles were competitively inferior to the California mussels, and the community eventually (in about 7 years) returned to a dominant mussel community. Following a major disturbance, in the first 3-4 years, the recovering patches seemed to be relatively immune from major disturbance, due to the absence of California mussels initially, and the relatively low profile of the community. Wootton (1992) showed that gull predation on goose barnacles allowed California mussels an increased competitive advantage. Goose barnacles have been shown to negatively affect California mussels by gaining an initial size advantage, and appears to inhibit California mussels by restricting the shell opening and reducing the feeding ability of the mussels. Goose barnacles are also unsuitable for mussel attachment, as they periodically shed their exoskeleton, and they may filter out larval mussels before they can settle (Wootton 1993). Wootton (1993, 1994) also showed that while goose barnacles may affect the dynamics of mussel bed succession, they do not affect the end-point. As California mussels attain large size with time, the competitive effects of goose barnacles are reduced and competitive effects on goose barnacles become stronger. California mussels have a rigid external shell that, with increasing size, can outcompete goose barnacles by crushing them between mussel shells, or the barnacle body walls may rupture by abrading against the shell edge. Goose barnacles do not grow fast enough to fill all the available space before mussel settlement, and the mussels can gain a foothold in these areas. Mussels may also recruit to gaps from the surrounding areas as adults, and therefore be introduced to gaps at a relatively large size (Wootton 1993). Wootton (1997) showed the importance of determining strength interactions among species in determining community dynamics. Experiments with bird exclusion cages and subsequent path analysis showed that bird predation negatively affected goose barnacles, but not snails or California mussels. Goose barnacles reduced acorn barnacle and California abundance due to space competition. California mussels reduced acorn barnacle cover by competing for space. Acorn barnacles and goose barnacles enhanced snails as prey species, but snail predation did not have important effects on acorn barnacles or goose barnacles. In summary, it is very difficult to predict the extent and timing of community recovery following harvesting or natural disturbance, as the *Pollicipes-Mytilus* community is very complex, and evidence from the scientific literature suggests that recovery in each community studied appears to have unique characteristics.

While the rocky exposed coasts are the preferred habitat of goose barnacles, they also occur in other areas, such as rocks with the highest wave exposure in the San Juan Islands, Washington, more than 100 km from the open sea (Austin 1987, Lewis and Chia 1981). In some of these uncharacteristic areas, due to the nature and configuration of the rocky shoreline, steep cliffs are often cut by gullies extending well above the high tide level, allowing a unique opportunity for colonies to form in the backwash of the surging waves (Barnes and Reese (1960). They have also been reported on floats (Austin 1987), subtidally where tidal currents reach 16 knots (McDaniel 1985), and occasionally in large numbers in seawater intakes (Newman and Abbott 1980).

The cyprid larvae have a preference to settle and attach to adult peduncles (Barnes and Reese 1960, Lewis 1975, Hoffman 1984), giving them a degree of protection from desiccation, predation, and strong wave action. Hoffman (1984) found a size gradient of newly settled juveniles on adult peduncles, with smallest and most abundant positioned immediately adjacent to the capitula, and the largest and fewest in number positioned basally near the attachment disks. This is suggested to be the result of movement of juveniles from the capitular end to the basal end of the peduncle with increasing age and size. Hoffman (1989) found juvenile barnacles still attached to adult peduncles with rhizoid-like peduncular extensions extending downward from the adult peduncle. These extensions also appeared to carry ducts from the cement glands that attach the animals to new sites on the substratum. Hoffman (1984) also found the presence of individuals within aggregates that were not attached to the substrate or adult peduncles, but entwined among the peduncles of adjacent barnacles, and had their attachment areas expanded into bulb-like organs.

The preferential attachment of larvae on adult conspecifics appears to not only give a high degree of protection for very young juveniles, but also to provide an effective conduit for eventual attachment to the primary substratum in a highly competitive environment (Hoffman

1989). In a homogeneous barnacle environment, there is little space between peduncles for juveniles to attach. As previously reported, the homogeneous aggregations of barnacles are typically tightly formed humped clusters with the large older individuals at the centre, surrounded by a gradation of smaller younger individuals at the periphery (Bernard 1988). However, in a mixed barnacle-mussel community, the convex bivalve shells may limit the space available for the larger adult barnacles, and yet provide room for the smaller juveniles radiating from the adult peduncles (Hoffman 1989).

2.1.4 Parasites and Disease

No information was found on parasites or diseases of goose barnacles, as there have not been any studies investigating the possibility. However, there are very likely disease and parasites in goose barnacles (S. Bower, *pers. comm.*).

2.1.5 Food, Feeding Habits

The orientation of goose barnacles on the rocks is determined by the micro-topography surrounding each cluster. In areas where there is a distinctive runoff pattern following breaking waves, the dominant orientation of the animals is the position where the anterior face of the capitula faces the run-off water of retreating waves. In areas of turbulence where there is no distinctive runoff, there is no dominant orientation. The orientation of the animals to the run-off of waves rather than the initial breaking waves allows a longer feeding time (Barnes and Reese 1960). Adults depend on exogenous mechanical stimulation, such as wave action or moving prey to initiate feeding activity, which is then maintained by a flow of water above a certain level. There is no regular cirral beat in adults, unlike most other barnacles, but there is captorial macrophagous feeding by cirral extension, where under appropriate conditions, the cirri are extended and the body is raised in the mantle cavity (Barnes and Reese 1959). When the anterior face of the cirral net is held at right angles of the prevailing water flow, then there is both the maximum chance of trapping planktonic or dislodged benthic material and the greatest efficiency in food transport to the mouth by the cirri (Barnes and Reese 1960). Barnes and Reese (1959) give a very detailed description of feeding activity with the cirral net.

Lewis (1981) showed that juvenile goose barnacles are microfeeders, using cirral pumping and slow cirral beating, and gradually shifted to a macro-feeding extension and lasso method. As juveniles grew, the frequency of cirral beats decreased, to intermittent beats at, 10 - 12 mm rostral-carinal (RC)(Fig 1) length, and no evident beats at 14 mm or greater RC length. There may also be a partly respiratory function to cirral beating in juveniles. As was reported in the previous section, Hoffman (1984) found the most numerous and smallest juveniles immediately below the capitula, below the mean cirral net level of the adults (Lewis 1975). The juvenile cirral beating behaviour may be important in these crowded areas where competition with the macrophagous adults would be keen (Lewis 1981).

Lewis (1981) also showed a shift in food items concurrent with a shift in feeding behaviour. Particulate organic matter (< 10 μm), such as detritus and diatoms, composed 80 % of the midgut contents in the smallest (1-6 mm RC length) barnacles, and was found in decreasing proportions as the larger barnacles: 63% in the 7-14 mm RC length animals; and 52% in the 15-28 mm RC length animals. Large organic matter (10 μm - 5 mm), such as crustacea, barnacle exuviae, and copepods composed 8% of the mid-gut contents in the smallest (1-6 mm RC length) barnacles, and was found in increasing proportions in the larger barnacles: 31% in the 7-14 mm RC length animals; and 40% in the 15-28 mm RC length animals.

The most common food item of adult goose barnacles is small crustaceans (Howard and Scott 1959). Barnes (1959) found that adult goose barnacle gut contents consisted mainly of crustacean remains, as large as 500-1000 μm long, with small copepods, cirripede nauplii and cyprids common, and very little sand grains, diatoms and fine particulate debris present. Due to the size fraction of food items consumed by goose barnacles, it is unlikely that they would accumulate paralytic shellfish poisoning, as the causative dinoflagellate is too small for direct uptake (Bernard 1988). In California, concurrent tests for paralytic shellfish poisoning (PSP) in goose barnacles and California mussels from the same area at the same time, showed an accumulation of 85 μg toxin/ 100 g tissue in goose barnacles, compared to 6,400 μg toxin/ 100 g tissue in mussels. The results indicated that while goose barnacles could accumulate toxin from the food chain, it is unlikely to reach significant levels, and likely presents a minimal risk (Sharpe 1981 *in* Austin 1987).

2.1.6 Reproduction

Sexual maturity for goose barnacles is dependent on size rather than age and is attained at a rostral-carinal length of 14-17 mm. The age of maturity is from 1-3 years (Lewis and Chia 1981, Bernard 1988)

Goose barnacles are hermaphroditic, with eggs and sperm present at the same time, but self-fertilization does not occur (Hilgard 1960). Unlike many invertebrates, which release their gametes into the water in broadcast spawning, cirripedes typically reproduce by pseudo-copulation. This is initiated by searching movements of the penis, followed by acceptance of the penis of a functional male into the mantle cavity of a functional female (Barnes *et al* 1977). Hilgard (1960) found that copulation could occur in the largest animals only if the distance from the nearest was 8 inches or less. Lewis (1975) found that only those sperm that had been deposited into the mantle cavity could successfully fertilize the eggs. Lewis and Chia (1981) found that 60% of closely associated (up to 5 cm apart) adults contained embryo masses. Breeding was inversely proportional to distance at distances between 5 and 11 cm., and the maximum distance between individuals for potential breeding was 11 cm.

The oocytes are brought into a sac formed by the oviducal gland and they are fertilized in this sac (Barnes *et al* 1977). The egg is yolky and golden-orange. Before fertilization, it is irregularly shaped, and after fertilization it becomes spherical and then elongated, averaging 100 μm in diameter. The fertilization membrane lifts from the egg, becomes sticky, and egg lamellae (masses) are formed (Lewis 1975). In pedunculates, the egg lamellae may be attached to the epidermal wall of the mantle cavity, where the oviducal sac eventually breaks down and the nauplii are released as non-feeding, free-swimming planktonic stage I larvae (Barnes *et al* 1977). There is a very detailed description of cirripede reproduction given in a series of papers by Barnes *et* al (1977), Barnes and Barnes (1977), Barnes and Blackstock (1977a, 1977b), Klepal and Barnes (1977) and Klepal *et al* (1977). Lewis (1975) gives a detailed description of the embryogenesis of *P. polymerus*.

Cimberg (1981) found two physiological races of goose barnacles in California: a northern race, with maximum brooding activity at cold seawater temperatures (14 °C or less); and a southern race, with maximum brooding activity at warmer temperatures (20 °C). In California, Hilgard (1960) found brooding activity from May until December, with the average individuals producing 3 or 4 broods per year, and 104,000 - 240,000 larvae produced per adult per brood. In the San Juan Islands, Lewis and Chia (1981) found brooding activity was first evident in April, peaked in July, and decreased until cessation in November. There was no activity between November and March. Mean breeding activity was 53.4 % between April and October, with a peak of 77.4 % in July. The mean number of broods was 3.3, producing an estimated 144,000 - 288,000 embryos per adult per brood. Lewis (1975) found hatching of the nauplii ranged from 20 to 30 days after fertilization, with a mean brooding time of 25.4 days. At Amphitrite Point, Bernard (1988) brooding individuals were present throughout the year, but occurred most frequently from May to November, when 60% of the adult population may be brooding. Brooding appears to take 50 to 60 days in this area, with 2 to 5 broods produced annually. Lewis (1975) describes 6 naupliar stages, which are in the plankton an average of 42 days (at 12 °C ambient temperature), and settle out as cyprid larvae, with a high preference for adult peduncles as a substrate. It is estimated that with an average current speed varying between 0.1 and 0.5 knots, larvae could disperse from up to 116 to 580 miles (Lewis 1975).

2.1.7 Growth and Age

The cyprid larvae are 0.5 mm at settlement (Lewis 1975). Growth in goose barnacles is usually determined by measuring the distance between the rostrum and the carina, called the capitulum, or rostral-carinal (RC) length (Fig. 1). This may be the most stable relationship, and the biometric variable that best represents linear growth (Cruz 1993), compared to total length, width or weight measured under a range of conditions (Austin *pers. comm.*). However, Austin (1987) found that some individuals may have a relatively large peduncle tissue mass, with a relatively small capitulum, and associated RC length, while other individuals may have a relatively large capitulum and relatively small peduncle tissue mass. The height of the capitulum, and the length of the peduncle vary significantly, depending on the site, intertidal height and exposure to wave surge (Bernard 1988). There are also examples of variations in the capitulum allometry, related to habitat (Chaffee and Lindberg 1980). While the RC length may often be the best indicator of linear growth, this is not always necessarily the case, depending on local conditions. It was originally believed that goose barnacles were extremely slow growing and only reached sexual maturity after 5 years, with a maximum age of 15-20 years (Barnes and Reese 1960).

In southern California, Hoffman (1989) found very rapid growth in newly settled juveniles on the inverted surface of rocks within one month of settlement, where juveniles > 9 mm RC length comprised > 50% of the total population. Lewis and Chia (1981) found that barnacles which settled early in the summer, reached an RC length of 11-15 mm after the first year in the San Juan Islands, and up to 17 mm on the west coast of Vancouver Island. Austin (1987) found similar growth rates (12-15 mm) after 11 months in Barkley Sound. Lewis and Chia (1981) also found that lower intertidal individuals reached a larger size than corresponding high intertidal populations at the same site. Following the initial spurt of growth in the first year, the growth rate was reduced to about 2 mm per year.

Bernard (1988) found rapid growth (4 -5 mm) within the first 5 months of settlement, and a length of 15 mm after the first year on the West Coast of Vancouver Island, followed by a marked decrease in growth rate to 2-3 mm per year. This is the only one study in the scientific literature that attempted to age goose barnacles. A growth study was conducted on 250 tagged individuals, and ageing was conducted on 25 individuals using annual check marks on the carina plate, using the process developed for fish otoliths (Chilton and Beamish 1982). However, this technique for ageing goose barnacles is somewhat tenuous, as the outer layers of the carinal plate have been shown to slough off periodically (Wootton 1993, Austin *pers. comm.*). Bernard's (1988) predicted RC length at age in years, from the von Bertalanffy (1938) equation is shown in Fig. 5, where K (the Brodie growth coefficient) = 0.35; L_8= 31.6; and t_0= -0.584. The relationship between RC length and weight is shown in Fig. 6. The preferred size for commercial harvesting (~ 4 cm total length) has an RC length of 22 mm (Bernard (1988). From Bernard's (1988) data, the maximum age of goose barnacles appears to be 12 years.

Darwin (1851) was the first to observe that goose barnacles grew by lengthening the stalk in an additive manner at the capitulo-peduncular junction. Chaffee and Lewis (1988) showed the various components of growth through a series of radioisotope and feeding experiments. Concentrated mitotic activity was seen mainly at the capitulo-peduncular junction, the growth zone, and also with thickening and small extensions at the base of the stalk, from ^{3}H-thymidine uptake. New spicule formation was seen in the stalk exoskeleton at the capitulo-peduncular junction from ^{45}Ca incorporation. All animals showed a small organic component in the matrix component of spicules from $^{35}SO_4$ incorporation. Distinctive coloured bands at the top of the peduncle were related to varying diets in the feeding experiments. The growth area of the peduncle near the capitulo-peduncular junction with newly produced cuticle and spicules plays a particularly important role in providing a suitable settlement site for cyprids (Chaffee and Lewis 1988).

2.1.8 Recruitment and Mortality

Connell (1985) defines settlement as the point when an individual first takes up permanent residence on the substratum and recruitment as the measure of survival of individuals for a period of time after settlement. Recruitment combines settlement with early mortality. Pineda (1994) found that settlement rate of goose barnacles alone, was highly complex, and requires a knowledge of the larval pool, physical transport processes, micro-hydrodynamics, substrate availability and behavioural processes

Both anecdotal information and scientific studies show that recruitment of goose barnacles is highly variable. Anecdotal information from harvesters on the west coast of Vancouver Island indicates successful recruitment in some areas a year after harvesting, while adjacent areas may show no recruitment for over 6 or 7 years (Leonard Pavio, pers. comm.). Austin (1987) found successful recruitment (100% cover) at only 1 of 5 sites, with varying recruitment at the remaining 4 sites, in Barkley Sound and Clayquot Sound 11 months after harvesting. Successful recruitment was seen both on adult peduncles and on the acorn barnacle *S. cariosus.* Four years after harvesting, Austin (1992) found that most of the previously harvested areas could not be distinguished from unharvested areas.

Bernard (1988) found a very high juvenile mortality in newly settled juveniles, with numerous small (< 1mm) goose barnacles initially present on adult peduncles, cleared quadrats, lamelarian fronds, coraline algae, and generally on any hard substrate. Within 6 weeks, virtually all had disappeared, likely due to heavy predation. Hoffman (1989) also found very high mortality on newly settled spat within 2 or 3 weeks. On Amphitrite Point, settlement occurred throughout the year, with very low numbers in January and February, followed by a significant peak in March, major peaks in June and July, and continued evidence of settlement in December (Bernard 1988).

Hoffman (1989) found that goose barnacle settlement and recruitment was a function of tidal exposure, with a tendency for greater survival of juveniles (1-9 mm RC) in the lower midtidal. There was a direct relationship between aggregate size and spat settlement, however survival from spat to juvenile was higher on solitary adults than in the large mixed barnacle-mussel aggregates. Satchell and Farrell (1993) also found a direct relationship between aggregate size and spat settlement density.

Due to a lack of data, the only way to estimate natural mortality of goose barnacles is with Hoenig's (1983) generalized mortality model, using the predictive equation:

$$\mathbf{ln\ (z) = a + b\ ln\ (t_{max})} \quad \text{where for all taxonomic groups: } \mathbf{a = 1.44;\ b = -\ 0.982}$$

From Bernard's (1988) data, the maximum age is likely 12 years, and solving the equation results in a natural mortality estimate of 0.37. It should be noted that Hoenig's model is from combined data for molluscs, fish and cetaceans.

2.1.9 Density and Biomass

There is very little available information on density and biomass estimates for goose barnacles. Only two studies (Austin 1987, Bernard 1988) were conducted in the 1980s in order to assess the feasibility for a commercial fishery on goose barnacles. These studies included site surveys, with preliminary density and biomass estimates limited to a relatively small area of the west coast of Vancouver Island. Site surveys conducted at 5 sites in Barkley Sound and Clayquot Sound estimate densities ranging from 1,810/m^2 to 3,863/m^2 (Austin 1987). Population estimates at two small islets in Clayquot Sound yielded 1.5 million goose barnacles over 207 linear m shoreline in 594 m^2 habitat on one islet, and 2.4 million goose barnacles over 126 m linear m shoreline in 873 m^2 habitat on an adjacent islet (Austin 1987). Estimated densities are 2,563/m^2 and 2,797/m^2 respectively. Bernard's (1988) biomass estimates ranged from 2.7 kg/m^2 in mixed goose barnacle/California mussel clusters to 12 kg/m^2 in goose barnacle clusters.

3. Fisheries

3.1 Review of Goose Barnacle Fisheries in British Columbia

First Nations people have historically used goose barnacles on the west coast. The Nootka people pried goose barnacles off rocks at certain places, and it was considered that goose barnacle harvests were improved by repeated harvesting (Arima 1983). The Manhousat people considered them excellent eating. Eventhough goose barnacles were common in many places along the exposed outer coast, they were only harvested at certain specific locations with a prying stick off the rocks. Repeated harvesting was thought to improve subsequent harvests. Goose barnacles were considered too salty to be eaten raw. They were usually steamed briefly in a pit, but they were also occasionally roasted over alderwood coals beside a fire, imparting a smoky taste. Today they are briefly steamed or boiled in a pot (Ellis and Swan 1981). The Skidegate people also harvested goose barnacles from specific places by scraping with a digging stick. Goose barnacles were occasionally eaten raw, but usually cooked (always briefly) by roasting next to a fire or by immersing in boiling water (Ellis and Wilson 1981).

The recreational harvest of shellfish, including goose barnacles, is regulated by the British Columbia Sport Fishing Regulations made under the Fisheries Act. A DFO Tidal Waters Sport Fishing licence is required for the recreational harvest of all shellfish species. The present-day recreational goose barnacle fishing limit is 2 kg. per day, with a possession limit of 4 kg.

A research fishery was conducted on the West Coast of Vancouver Island in the mid 1980s to determine the feasibility of a commercial fishery on goose barnacles (Austin 1987). In Barkley Sound test fishing, harvesters removed between 2% (0.32 m^2, 7.7 Kg) and 8% (6.7 m^2, 16.4 Kg.) of the population at 7 sites, with effort ranging between 1 and 13 man-hours. "Natural removals", defined as areas of absence of goose barnacles clearly within existing continuous populations where removal by previous commercial harvesters was considered unlikely, varied between 1% and 19% (Austin 1987). A similar test fishery at 2 sites in Clayquot Sound resulted in removal of 0.1 - 0.2% of the population, with effort ranging from 4 to 25 man-hours. It was estimated that only 25% of the sites with goose barnacle populations were considered worth harvesting (Austin 1987).

A very important factor in this fishery is the product quality. Goose barnacles vary considerably in body shape and size due to local growing conditions and wave exposure. Stalk configuration determines the consumer product quality of goose barnacles. Thicker stalks are considered to be better quality product. Austin (1987) showed what is considered to be premium quality, acceptable product and unacceptable product by comparing stalk length, width and volume. In the research fishery, the proportion of the harvest considered acceptable ranged from 25% to 73% by weight (mean 50% for 28 samples) and 21% to 64% by number (mean 49% for 11 samples) (Austin 1987).

The present-day commercial goose barnacle fishery has unlimited entry, with a category "Z-6" Goose Barnacle licence (fishing without a vessel), a Fishers Registration Card (FRC), and a Harvest Log as requirements for commercial harvest. Fishing gear is restricted to hand tools and hand picking only, with no power or mechanical devices permitted. Harvest by diving is not permitted. The fishery is presently open year round, from January 1 to December 31. There are permanent area closures listed in the 1998 Management Plan for Goose Barnacles.

A summary of the history of the goose barnacle fishery is shown in Table 1. The number of licences issued peaked at 467 in 1988, but this has since declined to 56 in 1996, 49 in 1997 and 36 in 1998. Despite the large increase in the number of licences issued in the late 1980s, there is no accurate information on the actual number of fishers actively participating in the fishery prior to 1990. Harvest log information indicates only 20 licences with reported landings in 1996, 19 licences with reported landings in 1997 and 12 (from fish slip data) with reported landings to date in 1998. Due to the nature of this fishery, and the relatively high value (> $9.00/ kg.) of the product, it is suspected there is considerable under-reporting of the catch. Both fish slip and harvest log data for this fishery are incomplete.

Fishing effort (as measured in fishing days from fish slips) has declined since 1991, when effort peaked at 3070 days (Table 1). In 1996, 574 fishing days were reported, and in 1997, 427 fishing days were reported. The preliminary 1998 data indicates only 215 fishing days reported to date. It is not possible to accurately determine the true CPUE for this fishery, due to unreported effort.

Annual landings by Management Area are shown in Table 2. Total annual landings (reported from fish slips) between 1987 and 1997 range between 8 and 49 tonnes. The preliminary fish slip data for 1998 indicate landings of only 3.9 tonnes. Historically, the majority of the total annual catch (92%) has come from the West Coast of Vancouver Island (Statistical Areas 23,24,26). In 1994, an exceptional amount, 8.8 t (31% of the 1994 annual catch), was landed in Area 1. Since 1996, landings in the south coast were reported monthly. Harvest log data in Table 3 show a small but fairly consistent market demand.

It should be noted that there are discrepancies between the sales slip and harvest log data. A preliminary examination of the 1997 and 1998 data show more serious discrepancies, which need to be resolved before any analysis is started. For example, in the 1998 fishery, 36 licences were issued, and to date (Dec. 16, 1998), only 12 fish slips and 4 harvest logs have been submitted, eventhough there is a requirement for monthly reporting. An examination of the export records from the Canadian Food Inspection Agency shows considerably larger amounts of product being reported as exported, in comparison to the amount of product being reported on sales slips. However, the exported weights were not verified, and some export certificates may have been cancelled, therefore the actual amount exported is not known.

3.2 Review of Goose Barnacle Fisheries in Alaska and Washington

There are no commercial goose barnacles fisheries in Alaska (B. Bechtol, *pers. comm.*; D. Woodby, *pers. comm.*). While goose barnacles do occur in SE Alaska, along the outer coast, conditions are marginal, as they do not appear to neither persist from year to year, nor do observed individuals grow to a very large size. Individuals exceeding 2.5 inches in length are uncommon (R. Larson, *pers. comm.*). There are no commercial fisheries for goose barnacles in Washington (B. Sizemore, *pers. comm.*), but there is a recreational fishery. The season in Puget Sound is open year round, and open Pacific coast beaches, the season is open from November 1 to March 31. The daily limit is 10 lbs. whole, or 5 lbs. of barnacle stalks. There is no minimum size limit (WDFW 1998).

4. Discussion

The goose barnacle fishery has been an unlimited fishery in every respect since its inception. There is unlimited entry, the fishery is open year round, and there are no size limits (apart from market preferences). This is not a new fishery, as goose barnacles have been fished since 1978 and landings have been reported since 1985. The fishery initially grew rapidly and peaked in 1988, with 467 licences issued and reported landings of 49 tonnes. Since 1995, landings have been 8 - 10 tonnes per year, excluding the 1998 fishery, as statistics are not yet complete.

While a historic trend can be seen in the goose barnacle fishery, with a peak in the late 1980s, and declining to relative stability in recent years, it is impossible to assess the actual magnitude of this fishery, due to inconsistencies between the fish slip database and the harvest log database. Experienced harvesters estimate less than 50 % compliance with harvest log submission (T. Hamilton, *pers. comm.*).

This fishery is of relatively high value for fishers (> $9.00/kg.), but the fishery is limited by a small niche market with demands for live high quality product. It is estimated that less than 10% of the stock is available to the fishery due to inaccessible harvest areas, and/or unsuitable size and quality of product for the market (DFO 1998). The major fishing activity has been carried out along the West Coast of Vancouver Island in Statistical Areas 23, 24, and 26, mainly due to product availability, quality concerns and proximity to markets. The logistics of shipment of live quality product has, in part, restricted expansion of this fishery to other areas, such as the North coast.

This fishery is a low priority for the Conservation and Protection Sector. Concerns that have been identified include harvester licensing, and lack of compliance in catch reporting on fish slips and harvest logs. Experienced harvesters are also concerned with local stock damage caused by inexperienced harvesters who are attracted by the high value of the fishery, and are only interested in short-term high yield gain (T. Hamilton, *pers. comm*. L. Pavio, *pers. comm*.)

4.1 Biological Considerations

Given the uncertainty of settlement and recruitment seen in goose barnacles, and the highly variable recruitment patterns seen in goose barnacles following harvests (Austin 1987, Bernard 1988, Austin 1992, L. Pavio, *pers. comm*.), one must assume that there are many complex relationships (stock/recruitment, community interactions and other environmental factors) affecting goose barnacle recruitment. Goose barnacles are unique in comparison to most other crustaceans, in that fertilization is internal, there are particular proximity requirements for successful fertilization, and there are definitive periods of brooding activity. The issue of season needs careful consideration. Austin (1987) found that the best tides for harvesting occur in the morning during the summer months and after dark during the winter months. Night-time harvesting was attempted during the test fishery, but harvesters decided there was an insufficient safety margin. While the best tides occur during the summer months, this coincides with maximum brooding activity and settlement of larvae. The critical and particularly sensitive stage of newly settled cyprids, the breeding requirements and the brooding activity of adults should be considered in planning the type, timing, extent and duration of harvest activities. In light of this, and with previous observations on recovery times, a rotational fishery would likely be less detrimental than an annual one.

From a community standpoint, the effects of harvesting activities on co-occurring species should be evaluated. Harvesting goose barnacle adults attached to mussels and acorn barnacles has resulted in a higher quality goose barnacle product (Austin 1987), but it has also surely resulted in the mortality of the substrate species. Harvesting activities such as walking to and from the harvest site will result in mortalities to the species underfoot. Bernard (1988) found that removal of a segment of a goose barnacle cluster often results in the detachment and loss of the entire structure, either from predation or from wave surge. The size of the harvest patch in or near a mixed community may affect the stability of the remaining community, by allowing logs and other debris to undermine the community during storm surges. The *Mytilus-Pollicipes* community in particular has been shown to be a complex and productive habitat for a number of other species. It is difficult to predict the dynamics of successional changes may occur in this community following disturbance due to harvesting activities, and if and when recovery can be expected to occur.

4.2 Stock Assessment Considerations

There have been only 2 goose barnacle surveys on a small portion of the west coast of Vancouver Island (Austin 1987, Bernard 1988), as well as a test fishery (Austin 1987) for goose barnacles, and they were conducted in the mid 1980s. Anecdotal evidence from experienced harvesters indicates a decline in suitable stock in accessible areas. Anecdotal evidence from an experienced harvester a few years ago, indicates potential for fishery expansion to areas of the North coast and the Queen Charlotte Islands, however shipping logistics and potential resource use conflicts remain to be resolved. Preliminary estimates of stock availability to the fishery have declined from 25% in the mid 1980s to 10 % at present.

Data is available on growth, but this has been shown to be highly variable and dependent on local conditions. There has been only one study that has attempted to age goose barnacles with a degree of accuracy (Bernard 1988), and information from this study was used to make a crude estimate of natural mortality from a generalized model that may or may not be applicable. Since growth and mortality estimates are critical parameters in setting the harvest rates, it is important to have an accurate and realistic estimate of growth and natural mortality for local conditions. Instantaneous natural mortality estimates can be derived from a catch curve regression of age-frequency data, but this will require fairly difficult ageing techniques on fairly large sample. Growth and natural mortality could also be determined from marked experimental plots.

There is very little information on recruitment, recruitment variability and the effects of fishing on recruitment, and what information is available is often conflicting. Repeated surveys of experimental plots, where there is no fishing, and fishing at various exploitation rates could be used to assess recruitment. In addition, the role of critical threshold levels should be investigated.

Results from a test fishery showed that on average, 50% of the harvest was not acceptable product. There is anecdotal information on large amounts of product being harvested, which is not commercially acceptable, resulting in high discards (Austin, *pers. comm.*). An accurate assessment of proportion of the harvest that is discarded is required to obtain an accurate estimate of total fishing mortality.

4.3 Management Strategies

This fishery is virtually an unmanaged fishery. It has unlimited entry, no size limits, no quotas or TACs, and it is open year-round. The fishery is only limited by market demand and accessibility to suitable product. The only management measures are permanent area closures (applicable to all fisheries), gear restrictions limited to hand tools or hand picking, and a requirement for catch reporting. There is evidence of relatively low compliance for catch reporting. The high initial participation rate and high reported catches, followed by a decline to present levels, has all the classic signs of a “gold-rush” fishery.

A number of experienced harvesters had formed a goose barnacle co-operative to work on the marketing and management of the fishery a few years ago, but due to the untimely death of one of the founders and head, the co-operative has been relatively inactive. This group, presently 15 harvesters, has become active again hoping to address the following issues: renewed conservation concerns; activities of inexperienced harvesters; low catch reporting compliance; requests for licence limitation; requests for surveys and biomass estimates; and sales and market problems. This group has recently received funding assistance from Fisheries Renewal B.C. DFO has also encouraged this group to form a goose barnacle sectoral committee to deal with coast-wide concerns within this fishery. This group could provide important information on stock strength, conservation concerns, management changes and economic development. The renewed activity of this group is particularly timely, with the consideration of stock assessment initiatives and management strategies.

In consultation with the goose barnacle co-operative, interim management strategies to be considered for goose barnacles should include: demonstrated proficiency at harvesting suitable product to reduce discard mortality; close monitoring of exploratory fishing areas; time and area closures; implementation of rotational harvesting; and permanently closed areas in order to monitor regime shifts, protect broodstock and protect particularly sensitive communities. This fishery should remain a small fishery restricted to small areas, until stock assessment information is collected and analysed, and appropriate management strategies are developed for the long-term sustainability and stability of the fishery

In order to collect data for stock assessments, including repeated surveys and biological information, mandatory participation of trained harvesters should be considered before fishing. This would give harvesters an appreciation for the requirements of scientifically rigorous information, as well as providing the opportunity to incorporate and confirm historical, traditional and anecdotal information. Harvesters would have an active role in stock assessment activities and assist in developing management strategies for a stable, and sustainable goose barnacle fishery.

5. Conclusions

The overall status of goose barnacles stocks in British Columbia is unknown, as there is insufficient data for assessments. The information gaps identified through this review include the distribution of goose barnacle stocks, estimates of biomass, total fishing mortality, and an updated estimate of proportion of the stocks available to the fishery. While there is some limited information on recruitment, recruitment mechanisms are unknown, as well as the dynamics of recovery following harvesting or disturbance. There is also limited information on growth, and very limited information on age structure and natural mortality. Additional data is required in order to accurately assess these two parameters in order to set precautionary harvest rates.

There are presently no fishery controls. The impact of harvesting is unknown with respect to sustainability and ecological considerations.

Given that there are not sufficient data to recommend biologically based management for goose barnacles, more precautionary measures, including new management controls and assessment programs should be considered, in order that the goose barnacle fishery follow the phased approach described in the Pacific Region Policy for New and Developing Fisheries. These include:

- strictly enforce catch reporting as a condition of licence;
- accurate estimates of total fishing mortality;
- conduct surveys of goose barnacle populations to determine distribution, density, availability of suitable stock to the fishery, recruitment rates, and potential community interactions;
- conduct habitat assessments in proposed fishing areas to ensure sensitive habitats are protected from harvesting and related activities;
- design exploratory fisheries, in consultation with stakeholders, to determine the distribution of accessible and suitable stocks, and to collect detailed catch information;
- collect biological samples from key index sites (both fished and unfished) to monitor the effects of fishing on population structure, and to develop an understanding of recruitment;
- investigate the appropriateness of critical threshold levels.

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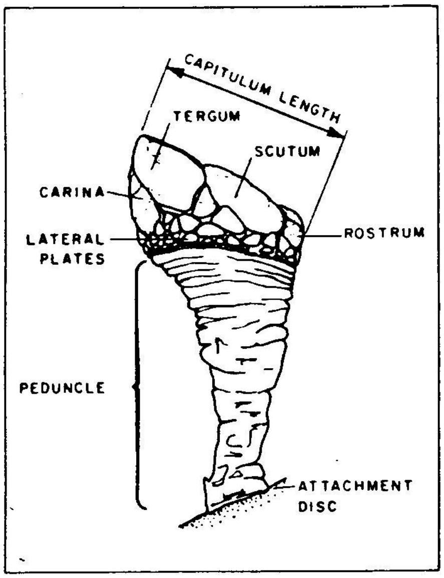

Fig. 1. Schematic lateral view of the goose barnacle showing the principal parts and measurements used. (from Bernard 1988)

Fig. 2. Juvenile goose barnacles growing on the adult peduncle from the West Coast of Vancouver Island, near Tofino, April 1999. (R.Lauzier photo)

Fig. 3. Distinctive clumps of goose barnacles on the West Coast of Vancouver Island, near Tofino, B.C. April 1999. (R.Lauzier photo)

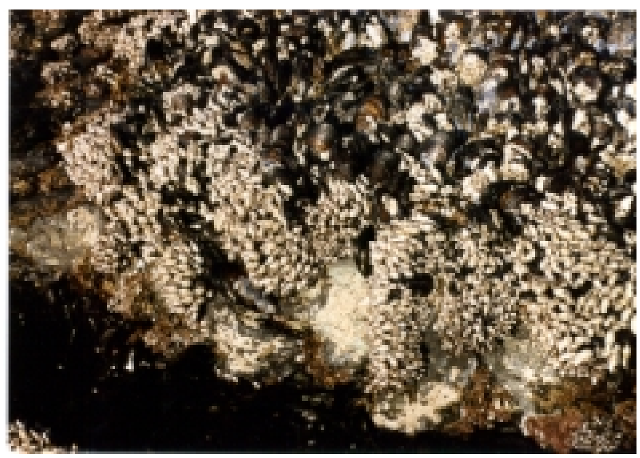

Fig. 4. Goose barnacles on overhanging surface with adjacent California mussels on near-horizontal surface on the West Coast of Vancouver Island, near Tofino, B.C. April 1999. (R.Lauzier photo)

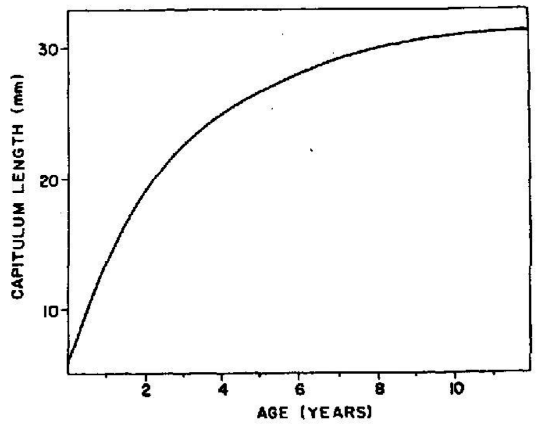

Fig. 5. Predicted RC length at age in years from the von Bertalanffy equation for goose barnacles from Amphitrite Point, B.C. (from Bernard 1988)

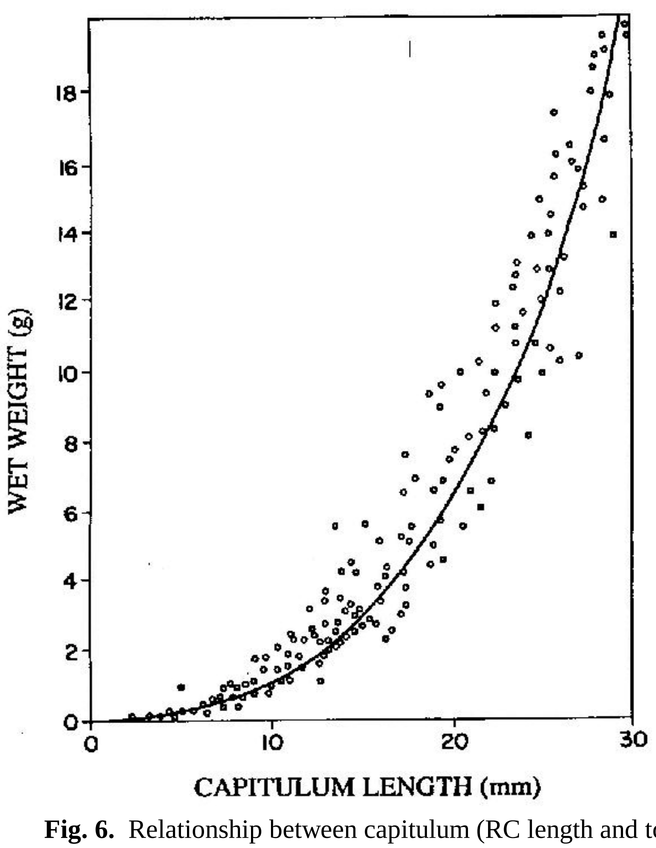

Fig. 6. Relationship between capitulum (RC length and total drained weight of goose barnacles from Amphitrite Point, B.C. (from Bernard 1988)

Table 1. Goose barnacle landings (tonnes) and effort for British Columbia, 1985 to 1998, as reported on fish slips and harvest logs.

Year	Type and Number of Licences Issued	Number of Licences with Landings	Fishing Days[1]	Landings[2] (t)	Landed Value[1] ($$10^{-3}$)	Whole Landed Value[1] ($\$*kg^{-1}$)
1985	9 Z	--	145	1	1	1.00
1986	25 Z	--	77	2	4	2.00
1987	221 Z	--	798	32	211	6.56
1988	467 Z	--	1596	49	479	9.78
1989	130 Z-6	--	713	30	343	11.43
1990	137 Z-6	49	2278	37	413	11.14
1991	131 Z-6	30	3070	41	418	10.31
1992	125 Z-6	39	1878	38	448	11.80
1993	105 Z-6	32	2049	30	320	10.67
1994	114 Z-6	37	1482	28	273	9.79
1995	65 Z-6	7	321	8	79	10.30
1996	56 Z-6	20	574	12	112	9.08
1997	49 Z-6	19	427	10	99	9.85
1998	36 Z-6	12	215	4	34	9.04

[1]from sales slips only
[2]from harvest log and sales slip data
[3]1998 preliminary data only

Table 2. Annual gooseneck barnacle landings (tonnes) by Management Area 1985 to 1998, as reported on fish slips.

	MANAGEMENT AREAS															
	North Coast						South Coast									Annual
Year	1	2	5	7	8	10	11	12	20	21	23	24	25	26	27	Landings
1985																0.0
1986								1.2			0.2	0.2				1.6
1987			0.04					0.2	0.1	0.1	11.0	18.0	0.5	1.3	0.1	31.3
1988		0.2		0.1	0.1	0.7	0.4	0.5	0.2		6.6	19.0	3.0	17.0	0.9	48.7
1989		0.5		0.7	1.2		0.1	0.1			3.9	11.0	0.1	12.8		30.3
1990					0.4						8.0	13.0		15.0	1.0	37.4
1991								0.33			9.0	16.0	0.4	15.0		40.7
1992					0.2			0.4			2.6	5.7		28.5	0.2	37.6
1993		0.06					0.06				5.1	9.3		15.5	0.1	30.1
1994	8.8			0.2							7.5	4.8	1.4	5.1	0.1	27.9
1995											1.0	1.5		5.3		7.8
1996											3.5	6.5	0.2	2.1		12.3
1997								0.5			4.2	5.1	*	0.2		10.0
1998[1]											1.2	2.7				3.9
Totals:	8.8	0.8	*	1.0	1.9	0.7	0.6	3.2	0.2	0.1	63.8	112.1	5.6	117.7	2.4	

* less than 100 kg

[1] 1998 preliminary data only

Table 3. Summary of goose barnacle landings (tonnes) by month in South Coast Management Areas in 1996, as reported on fish slips and harvest logs.

	Fish Slips							Monthly	Harvest Logs							Monthly
Month	20	21	23	24	25	26	27	Totals	20	21	23	24	25	26	27	Totals
January			0.16	0.04				0.20			0.15	0.18				0.33
February			0.05	0.26				0.31			0.24	0.07				0.31
March								0.00			0.40	0.12				0.52
April								0.00			0.41	0.23				0.64
May			0.51	1.72				2.23			0.38	1.49				1.87
June			0.88	1.18		0.44		2.50			0.30	0.73	0.01	0.74		1.78
July			0.62	0.76		0.26		1.64			0.12	0.70	0.02			0.84
August			0.17	1.03		0.24		1.44			0.41	0.68		0.20		1.29
September			0.39	0.19		0.88		1.46			0.58	0.37		0.56		1.51
October			0.20	0.37				0.57			0.40	0.14				0.54
November			0.32	0.34	0.03	0.19		0.88			0.27	0.09		0.19		0.55
December			0.22	0.58	0.2	0.15		1.15			0.26	0.13				0.39
Area Totals			3.52	6.47	0.23	2.16		12.38			3.92	4.93	0.03	1.69		10.57