Fisheries and Oceans Canada
Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/209

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/209

Not to be cited without
permission of the authors[1]

Ne pas citer sans
autorisation des auteurs[1]

Phase 1 Framework for Undertaking an Ecological Assessment of the Outer Coast Rocky Intertidal Zone

Glen S. Jamieson[1], Ray Lauzier[2] and Graham Gillespie[2]

[1] Department of Fisheries and Oceans
Marine Environment and Habitat Science Division
Pacific Biological Station
Nanaimo, B.C., V9R 5K6
Canada

[2] Department of Fisheries and Oceans
Stock Assessment Division
Pacific Biological Station
Nanaimo, B.C., V9R 5K6
Canada

ISSN 1480-4883
Ottawa, 1999

Canada

Abstract

As a result of the Phase 0 review of the biology and fisheries of the goose barnacle (*Pollicipes polymerus* Sowerby, 1833) (Lauzier 1999a), the issues raised in the Phase 1 paper on sea mussels (*Mytilus californianus*) (Gillespie 1999) and the concerns expressed by the Invertebrate Subcommittee/Pacific Scientific Advice Review Committee (PSARC), the Resource Management Executive Committee (RMEC) recommended closing the goose barnacle fishery, and not to proceed beyond the harvest of sea mussels for biotoxin monitoring. The goose barnacle fishery was closed by Fisheries Management on May 30, 1999. Any re-opening or development of the goose barnacle fishery and continuation of the biotoxin monitoring using harvested wild sea mussels would depend on the results of an ecological impact assessment and meeting the criteria for a new and developing fishery. This Phase 1 framework for an ecological impact assessment is for consideration by the PSARC Habitat Subcommittee. A Phase 1 stock assessment and management framework was submitted (Lauzier 1999b) to the PSARC Invertebrate Subcommittee. Both documents will be used to provide an overall assessment framework for the potential re-opening and development of the goose barnacle fishery.

Here, we present a proposed research design and recommendations as to how the studies should be integrated with planned stock assessment research. This research document provides a brief history of both the goose barnacle and sea mussel fisheries, plus a literature review of the biology and ecology of both species. Included as well, is a scientific review of disturbances and recoveries in the rocky intertidal zone. Its important to note that considerable information is available from local studies of the goose barnacle, and in particular on impacts of harvesting. These reviews are followed by an approach for an ecosystem assessment of the rocky intertidal, which includes allowing a modest experimental fishery. Such a study should be preparatory to full renewable resource exploitation in this ecosystem. Criteria on which to develop a research design are proposed.

Résumé

Suite à l'examen (Lauzier 1999a) de l'étape 0 de la biologie et de la pêche du pouce-pied (*Pollicipes polymerus* Sowerby, 1833), aux questions soulevées dans le document de l'étape 1 (Gillespie 1999) sur la moule de Californie (*Mytilus californianus*) et aux inquiétudes exprimées par le sous-comité des invertébrés du Comité scientifique consultatif de la recherche dans le Pacifique (CSCRP), le comité exécutif de gestion des ressources a recommandé que l'on ferme la pêche du pouce-pied et limite la récolte de la moule à celle nécessaire au contrôle de la biotoxine. La pêche du pouce-pied a été fermée par la Gestion des pêches le 30 mai 1999. Toute réouverture ou développement d'une pêche du pouce-pied ou poursuite du contrôle de la biotoxine à partir de moules sauvages récoltées seront fonction des résultats d'une évaluation d'impacts écologiques et de la conformité aux critères d'une nouvelle pêche. Le cadre de l'étape 1 pour une évaluation des impacts écologiques fera l'objet d'un examen par le sous-comité de l'habitat du CSCRP. Un cadre d'évaluation et de gestion des stocks de l'étape 1 a été soumis au sous-comité des invertébrés du CSCRP (Lauzier 1999b). Ces deux documents serviront de

cadre général d'évaluation pour une réouverture et un développement possibles de la pêche du pouce-pied.

Nous présentons ici un plan de recherche proposé et des recommandations sur la façon dont les études pourraient être intégrées à la recherche prévue sur l'évaluation des stocks. Ce document de recherche donne une brève historique des pêches du pouce-pied et de la moule et comporte un examen des publications sur la biologie et l'écologie de ces deux espèces. On y trouve aussi un examen scientifique des perturbations et des rétablissements notés dans la zone intertidale rocheuse. Il est important de noter qu'une grande quantité d'informations peut être obtenue des études effectuées localement sur le pouce-pied et, plus particulièrement, sur les effets de la récolte. Ces examens sont suivis d'une démarche proposée pour l'évaluation écosystémique de la zone intertidale rocheuse, qui prévoit une pêche expérimentale modeste. Une telle étude devrait être un élément préparatoire de toute exploitation de la ressource renouvelable de cet écosystème. Des critères sont aussi proposés pour l'élaboration d'un plan de recherche.

History of Past Resource Exploitation

1. Goose barnacles

First Nations people have historically used goose barnacles on the west coast. The Nootka people pried goose barnacles off rocks at certain places, and they are reported to have considered that goose barnacle harvests were improved by repeated harvesting (Arima 1983). The Manhousat people considered them excellent eating (Ellis and Swan 1981). However, even though goose barnacles were common in many places along the exposed outer coast, they were only harvested at certain specific locations off the rocks with a prying stick. The Skidegate people also harvested goose barnacles from specific places by scraping with a digging stick.

A summary of the total reported landings of the recent commercial goose barnacle fishery from the sales slip database is shown in Fig. 1. Landings peaked in 1988 at 53.5 tonnes and declined to 8.5 tonnes in 1995, and recovered slightly in 1996 and 1997. 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. A summary of the historical effort of the goose barnacle fishery is shown in Table 1. The number of licences issued peaked at 467 in 1988, coincidentally with the peak in landings, but this has since declined to 56 in 1996, 49 in 1997 and 36 in 1998. 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 catch per unit effort (CPUE) for this fishery, due to unreported effort.

There are large discrepancies between the sales slip and harvest log databases, and Canadian Food Inspection Agency export records. 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.

2. Sea Mussels

Sea mussels (*Mytilus californianus*) were used as food and tools by aboriginal peoples, and had considerable spiritual significance (Ellis and Swan 1981; Ellis and Wilson 1981; Arima 1983; Burley 1989). Sea mussels were collected and eaten steamed in the shell or dried. Mussel shells were used as knives, hand chisels and other edge-cutting implements, as jewellery and possibly as arrowheads.

Bourne (1997) indicated that some minor attempts at commercial fisheries for both bay and/or sea mussels had occurred in B.C., and expressed doubt that fisheries for either species could be established because of harvesting economics and poor quality. Current harvests of sea mussels in British Columbia are limited to recreational fishing and collection of animals for biotoxin monitoring programs in support of other bivalve harvests (Gillespie 1999).

B.C. mussel landings are available, although the mussels are not separated to species [*i.e.*, landings may represent either sea or bay (*Mytilus edulis* complex) mussels, or a combination of species] from 1983-1990, after which mussel licences were no longer issued. Landings during this period averaged 0.9 t per year, with a maximum of 2.5 t in 1988. Recent harvests for Canadian Food Inspection Agency biotoxin monitoring programs averaged 2 t per year between 1996-1999, and did not exceed 3 t in any year. Harvest of mussels in the North Coast for industry-supported biotoxin monitoring programs currently go unreported. The recreational fishery is managed under a daily bag limit of 25 mussels (total possession limit is 50 mussels) in the South Coast, with a reduced limit of 12 mussels $person^{-1}$ day^{-1} in Pacific Rim National Park on the west coast of Vancouver Island. The North Coast is closed to mussel harvests, due to the lack of biotoxin monitoring programs. Recreational harvests are by hand-picking only.

Sea mussels have been identified as an under-utilised resource by the provincial government, and interest in fishery development has been advanced. A proposal to harvest sea mussels in B.C. was evaluated in 1999 (Gillespie 1999). Because of the longevity of sea mussels, the keystone position of mussels in the community and the sensitivity of the mussel bed community to disturbance, very low harvest rates and specialized means of responsible harvesting were discussed. Given the concerns outlined in the paper, and the recognition that the fishery would need to be intensively managed while only providing a small economic return (Stocker and Winther 1999), DFO decided not to proceed with a mussel fishery at that time.

Scientific Studies

1. Intertidal species zonation

The intertidal is a particularly unique habitat, since both marine and meteorological events influence it. Since sessile species cannot retreat with the incoming tide, they are submerged in sea water and exposed to the air on a cyclic basis. On typically sloped bedrock substrates, different exposure levels, to either air or the ocean, result in considerable species zonation, often over relatively short distances (< one metre) of vertical height above Chart Datum. Zonation is not only the result of an individual species' tolerance to hostile conditions but is also the result of their predator's tolerances to the same conditions. Where a species occurs in abundance may be as much the result of a de facto refugia from predation as to direct tolerance of hostile conditions. Typically, since marine, rather than terrestrial, predators are most abundant in a rocky intertidal habitat, the upper range of a species' distribution is the result of that species' tolerance to environmental conditions, while the lower range of abundance is the result of their predator's tolerances to environmental conditions. Intertidal range of occurrence of a species may thus be relatively site specific, and dependent on the mix of species which exists.

2. Sea Mussel Ecology

a) Habitat Preferences:

Sea mussels are distributed from Baja California to Southeast Alaska, generally inhabiting high energy, wave-swept rocky shores. The geographic distribution is limited by temperature extremes (cold in the north, warm in the south). Unlike bay mussels, sea mussels are intolerant of low salinity and siltation, and thus are confined to exposed coastlines (Harger 1968). Sea mussels form densely aggregated beds from the upper intertidal to subtidal depths. Mature mussel beds are spatially complex, often increasing in thickness from a single layer of mussels at the edge to several layers of mussels in the middle of the bed.

Adult mussels are attached to the substrate and each other by strong byssal threads. Mobility is low, limited primarily to expansion of bed margins: adult sea mussels are essentially sessile. Bed dimensions may be increased through limited movements of adults, or through displacement by crowding. Dislodged individuals may re-attach in the subtidal zone, but these individuals likely are not pioneers leading to the development of new subtidal beds. Populations are increased through successful settlement of new recruits and growth, exchange of adult individuals between distinct beds is not thought to occur. Sea mussels do form subtidal beds under special conditions, but intertidal and subtidal populations are not contiguous (Scagel 1970; Chan 1973; Paine 1976b, 1989). Most beds are intertidal, and often the dominant feature of the preferred habitat. Mussel beds are entirely available to either harvest or survey collection, except where shoreline gradient renders access dangerous.

The upper limit of the distribution is determined by the physiological tolerances of the mussels (temperature extremes, desiccation, length of time exposed during low tides). The lower limit of mussel distribution is thought to be determined by predation, and thus is dependent on the physiological tolerances of predators, primarily the sea star *Pisaster ochraceus* (Paine 1966, 1974, 1989; Robles *et al*. 1995).

Sea mussels are preyed upon by sea stars (particularly *Pisaster ochraceus*, but also *P. giganteus*, *Lepasterias hexactis* and *Pycnopodia helianthoides*), predatory whelks (*Nucella* [=*Thais*] *canaliculata* and *N. emarginata*), crabs, fish, oystercatchers (*Haematopus bachmani*), black turnstones (*Arenaria melanocephala*), surfbirds (*Apriza virgata*), glaucous-winged gulls (*Larus glaucescens*), western gulls (*Larus occidentalis*) and sea otters (*Enhydra lutris*) (Hewatt 1937; Harger 1972; Marsh 1986; Paine 1976a; Shaw *et al*. 1988; Seed and Suchanek 1992)

Sea mussels are efficient filter feeders, selectively removing food particles from the water column. Organic debris provides a large component of the mussel diet, followed by dinoflagellates, diatoms, silicoflagellates and bacteria (Coe and Fox 1942, 1944; Fox and Coe 1943). Other foods include tintinnids, flagellates, ciliates and other protozoans, algal cells and fragments, algal spores, spermatozoa and ova, and inorganic particles such as sand and shell fragments. Sea mussels efficiently extract and concentrate toxins from harmful algal blooms and faecal coliform organisms, and thus present a human health risk if not monitored carefully.

Sea mussels are broadcast spawners with pelagic larvae. Reproductive effort is generally expended at low levels throughout the year, with seasonal increases in the spring and fall (Whedon 1936; Young 1942; Yamada and Dunham 1989; Seed and Suchanek 1992). Because spawning is affected by ambient temperature and food ration, the seasonal variation may be more pronounced in B.C. than in Oregon or California. Larval period is approximately 3-5 weeks, thus larvae could potentially disperse far from their natal beds. Peterson (1984a,b) described preferential settlement of sea mussel pediveligers in spatially complex substrates, including clumps of bay mussels and the algae *Endocladia muricata*, and Petraitis (1978) demonstrated that juvenile sea mussels were more abundant in clumps of adult sea mussels than elsewhere. Recruitment pattern is one of several years of low recruitment occasionally punctuated by high recruitment events (Dayton 1971; Paine 1974, 1976a; Seed and Suchanek 1992; Robles *et al*. 1995).

Growth rates are affected by food availability, tidal elevation, temperature, competition for food in dense mussel beds and overgrowth by algal epiphytes (Dehnel 1956; Harger 1970; Elvin and Gonor 1979; Jamieson 1989; Dittman and Robles 1991). Size at maturity was estimated to be approximately 70 mm TL (Coe and Fox 1942), which can be achieved in one year in southern California. Because of latitudinal trends in temperature, growth in B.C. is expected to be considerably slower.

Mortality is likely highest in the planktonic larvae and recently settled post-larvae. Larger mussels have either grown through a size threshold that render them immune to predation by starfish, have shells thick enough to discourage predation by gastropods, or have settled high enough in the intertidal to effectively avoid predators (Paine 1976a).

b) Associated Species:

Sea mussel beds are the habitat base for a large community of associated species (Suchanek 1979, 1981, 1985, 1992, 1994; Yamada and Peters 1988; Paine 1989; Seed and Suchanek 1992). On the outer Washington coast, local neighbourhood diversity ranged from approximately 20 species at high intertidal protected sites to approximately 140 species at low intertidal exposed sites. In total, over 300 species inhabit the interstices of established sea mussel beds. Seed and Suchanek (1992) described the three primary components of the mussel bed community as:

1) the physical matrix of living and dead mussel shells (ranging in complexity from a monolayer to several successive layers);
2) a layer of accumulated sediments, mussel faeces and pseudofaeces, organic debris and shell fragments (termed "gorp" by Suchanek 1979); and
3) a taxonomically diverse arrangement of flora and fauna.

The physical complexity of a mussel bed increases as it grows older. Successive layers of mussels are added, attaching to neighbouring individuals, and progressively increasing spatial complexity and availability of microhabitats for use by associated species (Suchanek 1979; Seed and Suchanek 1992). Species richness increases with increasing mussel bed age and thickness, and decrease with increased intertidal elevation. Mussel beds also serve as a protective matrix which increases survival of small sea mussels, and thus increase recruitment rates.

Mussel beds regularly suffer episodes in which disturbance gaps are formed in the bed, usually through log battering, wave action, fouling, hummocking, or predation. Fouling by the algae *Fucus distichus*, *Laminaria* spp. and *Postelsia palmaeformis* and the barnacles *Semibalanus cariosus* and *Balanus nubilis* are greatly increased when mobile predators or grazers are at low densities (Witman and Suchanek 1984; Seed and Suchanek 1992). Hummocking, or raised mussel clumps secured to the surrounding bed only by byssal attachment to other mussels and not the substrate, may be the result of crowding and intraspecific pressure, or caused by the activities of porcellinid crabs (*Petrolisthes* spp.). Adjacent hummocks may be connected by tunnels, and are inhabited by vast numbers of crabs. They may also serve as initiation sites for disturbance gaps. Predation by sea stars and sea otters can cause disturbance gaps. Summer-formed gaps are smaller and form slower than winter-formed gaps, and winter gaps have a greater probability of increasing in size.

Mussel beds do recover from disturbance, and the rate of recovery is dependent on size of the gap, season in which the gap formed, intertidal elevation, angle of the substratum and intensity of larval recruitment (Seed and Suchanek 1992). Recovery of small gaps is rapid, through slumping or collapse of adjacent mussels. Larger gaps are dependent on some lateral movement of mussels into the gap, and thus require more time to recover. Extremely large gaps are recolonized by a succession of species, including diatoms, filamentous algae, barnacles and bay mussels. There follows a period in which the gap is dominated by bay mussels, balanomorph and goose barnacles, and whelks. Sea mussels eventually colonise (ca. 20-26 months after disturbance in the mid intertidal), continue to expand, and eventually reclaim the disturbed area (ca. 60-80 months to decades after disturbance).

Typical studies of disturbed sea mussel beds show little recovery over 3-5 years (Hewatt 1935; Sousa 1984). Major disturbances in the mid intertidal range may require 8-35 years to recover (Paine and Levin 1981). Large areas of bare rock or upper intertidal disturbances require many years (est. 5-100+ years [Yamada and Peters 1988]) before sea mussel beds can be re-established (Dayton 1971; Seed and Suchanek 1992). In the absence of disease, mortality among large mussels is infrequent, and primarily due to episodic disasters (shear forces from large waves, wave-propelled logs and debris, or exposure to extreme temperatures at low tide) which remove portions of beds and create patches of exposed substrate (Paine 1976a; Paine and Levin 1981; Robles *et al*. 1995). Although some of these events (storms, temperature extremes) are climatic in nature, they are essentially unpredictable.

Settlement or mortality rates of recently settled mussels may be more susceptible to environmental influence. However, given the postulated population structure (extreme longevity and numerous age classes) and recruitment patterns (extended periods of low recruitment punctuated by few episodes of massive settlement), declining trends in recruitment would be difficult to detect, even over the long term. Because adult sea mussels are sessile, and thus cannot migrate in response to environmental stresses, changes in distribution are purely a function of either increased adult mortality (short-term) or decreased settlement and senescence (long-term).

3. Goose Barnacle Ecology

a) Habitat, Ecological Interactions 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, 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, metasiltstone and argillite (Austin 1987).

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).

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, sea mussels and the acorn barnacle *Semibalanus cariosus* (Austin 1987).

In the lower midtidal, the purple seastar (*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 sea star 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 sea mussel and the bay mussel (*Mytilus edulis*) complex 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. An extensive review of these studies could be the subject of an entire paper. However, a summary of the literature will provide a background for developing a framework for an "ecological impact assessment" (if such is ever required) of harvesting on the exposed rocky intertidal.

b) Review of Pollicipes-Mytilus Community Interactions:

Dayton's (1971) extensive study provided an experimental evaluation of natural physical disturbances and species interactions in the rocky intertidal community along the Washington coastline. Space was the most important limiting resource. Competition for primary space resulted in barnacles being dominant over algae. Sea mussels required secondary space for larval settlement, including specific algae, barnacles or byssal threads. Sea mussels and acorn barnacles are capable of outgrowing the major gastropod predators and could eventually monopolize all the space. Sea mussels are also capable of growing over all other sessile species, and are potentially the dominant competitor for space in the exposed rocky intertidal community. However, the combined effects of *Pisaster* predation and natural disturbances such as log damage prevent this from happening. Continuous physical and biological disturbances characterized the exposed rocky intertidal community, creating an abundance of free space, and allowing a large number of species to utilize the same potentially limiting resource.

In Washington, Paine (1974) studied the relationship between sea mussels, the dominant competitor in the exposed rocky intertidal, and the purple seastar *P. ochraceus*, its principal predator, and how the interaction between the two species influenced the distribution and abundance patterns of co-occurring species. He reported that on horizontal mid-intertidal surfaces, sea mussels were 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 were dominant, as sea mussels could not persist. In common areas, goose barnacles are capable of co-existing with sea mussels for at least 6 years. Paine (1974) found that predation was found to enhance co-existence among potential competitors. Despite an apparently static state of mussel beds, it was found that there was a very dynamic nature to the ecological processes in the exposed rocky intertidal. This community structure was found to be biologically highly organized, rather than primarily determined by extrinsic physical forces.

When examining community structure, Paine (1980) looked at three different approaches in depicting trophic relationships:

1. connection webs, based mainly on observations, where all possible connections are made and strength interaction is rarely considered;
2. energy flow webs, based on measurements (many physiological) and literature values, and assumes importance is measured by the rate of energy transfer and competitive cross-links are not considered; and
3. functional significance or interaction webs, based on interaction strength verified by experimental manipulation.

The functional significance model was considered to be superior as it provided several insights in understanding complex, highly interactive, multispecies relationships. The model showed that cross-links were as important as the trophic links, trophic links were unequal in strength, and strong predictable interactions often lead to a high degree of complexity and diversity in community structure. Paine's (1980) closing remarks to the Third Tansley Lecture included the statement: "…pattern is generated by process".

In ecosystems, such as the exposed rocky intertidal, that are characterized by high diversity, localized disturbances often renew the limiting resource, in this case space, which results in a progression of species invasion and occupancy. Paine and Levin (1981) studied the dynamics of localized disturbances or patches in sea mussel beds in Washington. They showed the rate of recovery and type of recovery was dependent on the size of the patch. They showed that "catastrophic" disturbances of sea mussel beds provided a unique invasion opportunity for goose barnacles. However, goose barnacles were competitively inferior to sea 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 sea mussels initially, and the relatively low profile of the community. It appears that in communities that are subjected to moderate disturbance, there is a higher species diversity in comparison to communities subjected to either extreme. Little or very minimal disturbance results in a tendency towards a monoculture of the competitive dominant. When the spatial scale of the disturbance is large enough to include all species in the system, then species may be eliminated, reducing species diversity.

Paine (1989) summarized information resulting from his years of work examining within-bed dynamics of mussel beds. His studies show that: (1) mussel beds are subject to natural cycles of disturbance and recovery; (2) recovery is partially dependent on the availability of adjacent mussels; and (3) recovery rates are slower in the high intertidal and in areas of less wave action. In his discussion on the commercial exploitation of sea mussels, Paine (1989) suggests the following guidelines:

1. Harvesting should be restricted to very small (<100 cm^2) spatially separated patches;
2. Harvesting should be seasonal, restricted to late spring and summer months to reduce the potential enlargement of small patches by wave scouring;
3. Some mussels must be retained to enhance the natural settlement of larvae;
4. Harvesting should be limited to the lower two-thirds of existing beds, where recruitment, growth and recovery are greatest;
5. Predator (starfish) removal may substantially increase mussel production by allowing mussel beds to extend to the lower intertidal where growth is higher;
6. In a multi-layered bed, only the upper layers should be harvested, leaving the bottom layer.

Despite suggesting these guidelines, Paine (1989) argues against the development of a commercial sea mussel fishery, as natural mussel beds are important reservoirs of diversity, with a minimum of 300 species, and he believes that harvesting will inevitably lead to a substantial disappearance of mussel beds.

At Tatoosh Island, Washington, Wootton (1992) showed that gull predation on goose barnacles allowed sea mussels an increased competitive advantage. Goose barnacles have been shown to negatively affect sea mussels by gaining an initial size advantage, and appear to inhibit sea 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 sea mussels attain large size with time, the competitive effects of goose barnacles are reduced and competitive effects on goose barnacles become stronger. Sea 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 sea mussels. Goose barnacles reduced acorn barnacle and sea mussel 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.

4. Review of Scientific Literature on Disturbance in Rocky Intertidal Habitats

A broader perspective than a review of information on *Pollicipes-Mytilus* community interactions may be required for developing a framework for developing an ecological impact assessment of harvesting on the exposed rocky intertidal. There is a great deal of scientific literature dealing with the structure, function, processes and the effects of disturbance on rocky intertidal habitats, but a thorough review of these exhaustive studies could be the subject of an entire book. Therefore, only a very brief summary of relevant studies on natural and human-induced disturbance will be provided for additional background and perspective for developing a framework for developing an ecological impact assessment of harvesting on the exposed rocky intertidal.

Menge *et al*. (1994) investigated the keystone species concept on the central Oregon coast, by examining the variation in strength interaction between the purple seastar *P. ochraceus* and mussels *M. californianus* and *M. trossulus*. Keystone predation occurs when a predator indirectly increases the abundance of its prey competitors by consuming the prey. Keystone predation was found to occur in the most diverse subhabitats, the wave exposed sites, and in less diverse and more sheltered subhabitats, predation was found to be weak or diffuse. The structure of the exposed rocky intertidal community appears to be dominated by keystone species.

Menge (1995) assessed the importance of indirect effects in the rocky intertidal community. In his analysis of 23 interaction webs from the scientific literature, it was found that with increasing web diversity, each species interacted strongly with more species, was involved with more indirect effects, and was part of more interaction pathways. Nine general types of indirect effects were identified. Keystone predation and apparent competition were the most common indirect effects. Indirect effects accounted for 40-50% of the changes in community structure resulting from manipulations. Strong direct interactions and indirect effects produced roughly the same level of change in community structure, regardless of web complexity.

Berlow and Navarrete (1997) repeated Dayton's (1971) experiments in Washington, and conducted ancillary experiments to investigate the spatial and temporal variation in the processes which maintain bare patches in the rocky intertidal community. Their results showed that with small patches, whelks and limpets were consistently important in maintaining bare patches, and field measures of predator-prey interactions were strongly influenced by initial experimental conditions, whether the community was left intact or not. They also found that the process maintaining bare patches varied dramatically over spatial scales.

Berlow's (1997) experiments focussed on the interactions of succession in a central Oregon coast sea mussel community following mimicked natural disturbances. Berlow (1997) identifies three types of succession:

1. Canalized succession occurs if early species have strong and consistent effects on later species, and as a result the community may follow deterministic, repeatable patterns of change over time:

2. Externally driven succession occurs if extrinsic events override the effects of deterministic species interactions, and as a result, variation in successional pathways may be driven externally by stochastic variation in environmental conditions, recruitment, disturbance and other events;
3. Contingent succession if the direction and magnitude of species interactions depend strongly on the context in which they occur, and as a result, the interaction between the stochastic and deterministic processes may result in highly contingent and rarely repeatable patterns of succession.

The succession in the mussel bed showed complex patterns of historical effects. However, within this complexity, some consistent and repeatable successional trends were identified. Some canalizing or noise-dampening forces in the system included: physiological and/or life history trade-offs between dispersal ability and competitive ability; strong biotic interactions which buffered environmental variability; and compensatory responses of species within an important functional group. Noise-amplifying forces included: variable effects of predators; prey size escapes, and predator saturation. Berlow (1997) concludes that understanding the patterns and causes of consistency or contingency will be critical for our ability to manage variability in communities that undergo some anthropogenic disturbance.

All of these studies have demonstrated that field experiments have proven to be one of the most powerful tools in investigating the processes of the rocky intertidal community organization. We have restricted this discussion to studies conducted in the Pacific Northwest, in order to reduce potential questions and concerns about scale- and context-specific experimental information. Hopefully this information will provide us with an approach and guidelines to assess the impacts of harvests in the exposed rocky intertidal.

An additional topic that needs to be addressed is the scientific information on the effects of anthropogenic activities on the rocky intertidal. A literature search revealed that in the rocky intertidal communities, only recreational harvesting and trampling effects have been examined.

Andressi (1994) cites a number of studies that document the effects of human activities. Zedler (1978 *cited in* Addressi 1994) conducted trampling experiments at Cabrillo National Monument in southern California. Heavy foot traffic damaged the intertidal community. Algal mats, principally coralline algae, were damaged in proportion to the intensity of trampling. The algal mats trapped large quantities of sand, which provided habitats for a variety of burrowing and tube-dwelling animals. Trampling reduced the thickness of the algal mats, and loosened the holdfasts, which resulted in crushing the associated fauna and flora, and reduced the available habitat. Duran *et al.*(1987 *cited in* Addressi 1994) found heavy harvesting pressure on a carnivorous gastropod, keyhole limpets and sea urchins. When removal of the gastropod ceased, there was a dramatic reduction in mussels, its primary intertidal prey. Removal of the herbivores allowed intertidal algae to flourish. Addressi (1994) found that trampling and overturning rocks had considerable negative impacts for sessile organisms, especially algae. The density of organisms was very reduced in highly visited areas, due to collection, dessication or crushing.

Addressi (1994) also looked at changes in the community from 1971 to 1991, and found substantial decreases in both abundance and species diversity.

Lindberg *et al* (1998) documented the interactions between human activity, American Black Oystercatchers, limpets and erect fleshy algae in the rocky intertidal communities of central and southern California. The results of the experiments showed a complex of cascading influences in some rocky intertidal communities. Human activity seems to have disrupted the organizational structure from a complex organizational structure composed of oystercatchers, large limpets (*Lottia gigantea*), and small limpets (*Lottia* spp.), to an organizational structure dominated by a small limpet guild.

A number of authors have investigated the effects of trampling on rocky intertidal communities. Povey and Keough (1991) and Keough and Quinn (1998) found the brown alga *Hormosira banksii*, a keystone species in the south-eastern Australia rocky intertidal community was negatively affected by trampling. Schiel and Taylor (1999) studied the effects on a similar community in southern New Zealand, and found that trampling intensity had variable effects, and there was an interaction of season, location and the indirect effects of coralline algae reduction that contributed to recovery after disturbance.

Brosnan and Crumine (1994) studied the effects of human trampling on the upper intertidal algal-barnacle communities and mid-intertidal mussel communities on the Oregon coast. In the algal-barnacle communities, foliose (fucoids, *Mastocarpus papillatus*) algal species were more susceptible to trampling, in comparison to the turf form of *Endocladia muricata.* Non-trampled plots showed greater fluctuations in canopy cover than trampled plots. After an initial decline in trampled plots, only small changes in cover were seen. Algal cover increased steadily after trampling stopped. Trampling significantly reduced barnacle cover by crushing, but in the recovery phase, barnacle cover in the trampled plots surpassed the control plots due to recruitment. The sparse cover of small mussels did not recover from the effects of trampling in the upper intertidal. In the mid-intertidal mussel communities, the monolayered mussels appear to have suffered higher losses due to trampling, in comparison to two-layer mussel bed. Trampling caused mussel dislodgement and disturbed the surrounding mussel bed. Mussels continued to be lost from the trampling sites during the recovery phase of this study. This study showed that trampling interacts with natural forces such as storms, to increase the extent of the original disturbance. Trampling affected the community structure by shifting the algal community from foliose canopy species to algal turf or crust species. While trampling mimicked some aspects of natural disturbance, and communities can recover from the effects of trampling, the frequency and intensity can make trampling a particularly severe stress.

5. Goose Barnacles in British Columbia

a) Summary of Austin (1987) and Austin (1992):

The study reported in Austin (1987) was initiated to provide biological, harvest, holding and market data associated with the potential establishment of a new fishery for the goose barnacle *Pollicipes polymerus*. Most of the information presented was specific to goose barnacles, including general spatial distribution, densities, size characteristics of individuals, etc., with relatively little data relating to the relationship of goose barnacles to the exposed rocky intertidal ecosystem. Nevertheless, this study provides the most comprehensive data set to date on goose barnacles in British Columbia, as summarised below. Austin (1992) reported observations made while revisiting six Barkley Sound sites harvested in 1985 and described in Austin (1987). Precise areas harvested, based on photographs and field diagrams made in 1985, were compared. In addition, two 1985 sites were qualitatively assessed for recruitment and growth of goose barnacles one, two, three and four years after harvest, with observations reported in Austin (1992).

Study range: Austin's (1987) research was confined to Barkley and Clayoquot Sounds on the west coast of Vancouver Island and took place in 1985. Sites were in the outer parts of both locations, as goose barnacles only inhabit coasts with significant wave action. Sites in Clayoquot were mostly on islets around Vargas Island and sites in Barkley Sound, because of fishery closure zones in the Broken Islands and outer part of the Deer Group, were primarily located on more inner islets.

Goose barnacle harvest characteristics: Goose barnacles can attach directly to rock, but because harvesting of such barnacles generally resulted in rupturing of the peduncle (*i.e.*, the "neck"), preferred harvesting locations were where goose barnacles were attached atop acorn barnacles (S*emibalanus cariosus*). By undercutting through the acorn barnacles, clumps of goose barnacles and sea mussels (*Mytilus californianus*) could be removed from most rock surfaces. The goose barnacles could then be peeled of the acorn barnacle remnants, typically without damage to the goose barnacle. Goose barnacle harvest rates ranged from about 9-15 kg h^{-1}.

Preferred size product had a capitulum length of about 30 mm (SD ± 6); a peduncle length and width of about 60 (± 20) and 16 (± 5) mm, respectively; and a wet weight of about 20 (± 10) g. Acceptable quality product ranged from 25-73% by weight and 21-64% by number of individuals.

Goose barnacles deep within mussel beds were easier to harvest than those in more exposed situations. Summer tide levels were rarely a limiting factor for harvesting. Even though the lower intertidal height of goose barnacles was about 1.5 m, barnacles there were mostly either not growing on acorn barnacles or were too long in shape, i.e. of undesirable quality. Similarly, goose barnacles above the range of acorn barnacles were also mostly not harvestable. Depending on ware surge heights, goose barnacles could occur up to a height of 4.1 m, but most harvestable ones were in the intertidal range of 2.1-2.9 m. Harvesting also generally occurred on average substrate slopes of 15-45°, which resulted in average widths of harvestable goose barnacle populations of 3.3 m at 15°, 1.6 m at 30°, and 1.1 m at 45° slopes. On slopes >45°, proportion of sea mussels generally decreased, and while clumps of goose barnacles might be common, these clumps were mostly attached directly to rock and hence are not harvestable. Goose barnacles are mostly small or absent at semi-protected sites, while on exposed sites, about 25% of the area had potentially harvestable goose barnacles.

Goose barnacle harvesting impacts: At selected sites in Barkley Sound, areas harvested at the end of 1-13 man hour harvest periods (harvesters felt there was no commercial product left) had 2-8% of goose barnacles removed, while 1-19% of the population was estimated by Austin (1987) to have been removed at some recent time by natural causes, i.e. non-harvest reasons. Austin (1987) suggested a number of potential causative reasons for the natural removal of goose barnacles:

1) purple sea star (*Pisaster ochraceus*): Feder (1959) and Paine (1980) document this species has goose barnacles as a minor part of its diet.
2) Glaucous winged gulls (*Larus glaucescens*): Vermeer (1982) reported goose barnacles as a dominant food item on the west coast of Vancouver Island based on percent occurrence in faecal pellets.
3) Sea mussels: Dayton (1971) and Paine (1974) have demonstrated that sea mussels may outcompete and displace goose barnacles
4) Sea palms (*Postelsia palmaeformis*): this annual macroalgae may overgrow goose barnacles and possibly kill them (Dayton 1971, Carefoot 1977)
5) Acorn barnacles: Dead acorn barnacles, which attach by a membranous base rather than cement, overgrown by goose barnacles may detach from rocks during strong wave action, weakening the ability of a goose barnacle colony to remain attached to the substrate
6) Logs: Abrasion by logs has been documented to knock sea mussel clumps free (Dayton 1971), and this likely affects goose barnacles too.

Austin (1987) returned to two harvested sites in Clayoquot Sound and three in Barkley Sound 10 months after harvesting, and observed the relative sizes of harvested bare patches at 14 precise locations. Comparison with the sizes of these patches immediately after harvest showed possible increases in size (15 and 50%, respectively) at only two locations. All locations showed new settlements of acorn barnacles, but only four locations showed goose barnacle settlement, and only two locations, the two with the greatest acorn barnacle settlement, had substantial goose barnacle settlement (about 160 and 1600 m^2, respectively).

Natural densities of goose barnacles ranged from 2000-5000 barnacles m^{-2} at Austin's selected harvest sites. Generally, though, Austin estimated that over a large area, only 0.1-0.2% of the goose barnacle population in Clayoquot Sound, at least, would be harvestable.

Goose barnacle population dynamics: Growth rates of goose barnacles are not clear, as there are disagreements between studies. Barnes and Reese (1960) suggested 20-25 mm capitulum sized Californian individuals are about 20 y old, but it is not clear how they were measuring growth – they stated between apices of the tergum and carina but probably meant between the tergum and rostrum (the tergum and carina are adjacent to each other). Austin (1987) observed growth to 12-15 mm in < 11 mo, comparable to annual growths of 17 and 15 mm reported by Lewis and Chia (1981) and Paine (1974) for the west coasts of Vancouver Island and Washington, respectively. In older animals, growth rate slows. Paine (1974) reported 3 y old animals to be 30 mm on the west coast of Washington, while Lewis and Chia (1981) suggested that in Puget Sound, growth slowed to 1-2 mm y^{-1} after reaching a size of 13-15 mm. What this all suggests is that goose barnacle growth can be quite variable, depending on location and perhaps water conditions in a particular year. Austin observed the largest harvestable barnacles tended to occur in locations with both strong wave action and tidal currents.

Recovery of goose barnacles harvested sites: Austin (1992) noted that six years after harvesting, it was not possible to visually discriminate between harvested and unharvested sites. Subsequent undocumented goose barnacle harvesting could not be ruled out, but Austin noted that even prior to harvesting, localised bare patches occur in goose barnacle habitat. Barnacles harvested in 1991 averaged about 20% smaller in weight, but were comparable in size, than those harvested in 1985. Annual observations over four years indicated that where goose barnacle settlement occurs within a year after harvesting, commercial size product can reestablish in three years. However, immediate successful settlement was often not the case, and like growth rate, settlement rate appears quite variable and may be quite site specific

Associations with other species: Apart from describing that goose barnacles were most cost effectively harvested when they were attached to acorn barnacles, and that they competed with sea mussels, little mention is made of other species inhabiting the rocky intertidal.

b) Other studies:

The only other British Columbian study on goose barnacles was by Bernard (1988) at Amphritrite Point on the west coast of Vancouver Island from 1980-1986. He described some aspects of the biology of the species, and harvest characteristics. In particular, he noted that resettlement had not taken place in harvested areas during the seven years of his study, and suggested that resettlement may involve a slow process of ecological succession, with the goose barnacles being a climax stage. Because of this low resettlement rate, he suggested sustainable yield may be a smaller fraction of the standing stock than might be assumed if recruitment rates for other crustacean species are assumed.

A Proposed Approach for Ecosystem Assessment of the Rocky Intertidal to Evaluate the Implications of Renewable Resource Exploitation

Ecosystem characteristics should be assessed in two broad ways: description of the species mix and species characteristics in different trophic levels in a specific predetermined geographical area identified as part of the “ecosystem” being investigated, and the interspecies relationships, or functional connections and associations between species in this area. If compared to a living organism, the former would describe the size, general shape, and constituent organs and cell types, while the latter would describe the organism’s physiology, how the collection of discrete parts functioned as a viable entity, and life history characteristics such as growth, longevity and perhaps associations of the organism with other individuals and its environment.

Important in this consideration is rationalisation of the specific geographical area identified as the “ecosystem”. Because many species have extensive ranges and tolerances to different environmental conditions, few “ecosystems”, particularly in the marine environment, have clearly defined boundaries that will not be argued over by some individuals. There are obvious scale factors here too, but for practical purposes, ecosystems can be, and have been, generally defined in terms of specific physical features. Thus, in the intertidal, while the tops and undersides of individual rocks could be considered separate ecosystems, generally larger scale physical characteristics are used to differentiate ecosystems, such as discrete sections of shoreline with predominantly bedrock, boulder, sand or mud substrates. For the purpose of this report, we are interested in bedrock intertidal areas on coasts exposed to large wave and surge action, and define this as the relevant ecosystem being considered. Both species need a hard stable substrate to attach to, and both species seem to best survive in habitats where most large potential predators are frequently dislodged by wave action. Also, goose barnacles feed on only relatively large food items, which can only be suspended and brought to them in quantity by big breaking waves.

In an ecosystem assessment, the first stage is typically determination of the species mix present and general evaluation of the biologies and characteristics of these species. How many species, for example, are 1) relatively rare, i.e. are unique to the ecosystem being studied or have limited overall geographic ranges; 2) are particularly important for the persistence of other species, i.e. are obviously spatially structural species which create habitats for other species or which can otherwise be identified as keystone species; or 3) are only in abundance as specific life history stages (e.g. is the area an important nursery ground) or for specific life history events [e.g. is the area an important staging area (e.g. estuaries are important habitats where salmonid smolts adapt to salt water) or perhaps reproductive area (e.g. Dungeness crab often moult in eel grass beds for protection and egg-carrying female Dungeness crab often concentrate in specific areas to incubate their eggs)]? Answering questions such as this puts elements of the ecosystem into perspective and allows more specific evaluation of the ecosystem in terms of criteria previously identified as important. These criteria include COSEWIC classifications of rare or limited range species, *Oceans Act* classifications of important habitats worthy of protection (see Levings and Jamieson, submitted), and the presence and abundance of economically important species.

In this context, we have identified some general topic areas that we suggest should be investigated to allow comprehensive evaluation of the importance of goose barnacles and sea mussels, i.e. structural species, to the exposed bedrock intertidal in British Columbia. There may be more questions that arise from these studies as data are evaluated, but initial topics identified are as follows:

1. General Community Structure Questions Around Selective Harvests of Structurally Important Species

- *What is the scale of potential harvest areas relative to the entire area of distribution of harvested species, and in areas where harvests can occur, what are the scales of potentially harvested to unharvested areas?*

Data here is expected to be obtained in Phase 1 PSARC reports for the development of new potential fisheries, as it mostly relates to harvest potential for such species.

- *Which colony species recruit to newly exposed substrate following harvests, and what is the temporal pattern of such recruitment through the course of a year and over years?*

Species differ in their reproductive strategies, with some species spawning on mass over a relatively short time period and others having an extended spawning period, with no large spawnings (dribble spawners). Recruitment is often substrate dependent, with sea mussels, for example, seldom settling on bare rock but rather preferring to settle initially on encrusting algae. What species settle on a particular patch of available substrate may thus depend on both the time of year the area was bared and what other species, and their current sizes, that may have previously settled on the site.

- *What affects, if any, does colony harvest have on the "survival" of adjacent colonies?*

Sea mussels and goose barnacles form clumps because colonies are better able than are individuals to withstand being dislodged by wave action. However, as with blow downs in forests, there is scientific evidence that over time, depending on the size, seasonal origin and tidal height, bared patches in and amongst goose barnacle and mussel colonies may increase in size. As with forests, the probability of this occurring may be quite site specific and dependent on the size, age and nature of existing colonies, but the situations under which this may occur need to be understood.

- *What is natural colony species turnover (colony duration) in an unfished situation?*

It is not known how long colonies can persist. Individuals can be roughly aged (e.g. through tagging or reading of growth rings), but because individuals of a species may settle within a colony and gradually replace older individuals, perhaps as they die, age of individuals is not necessarily an accurate reflection of colony age. Colony persistence may affect overall population production parameters.

- *How does colony biodiversity change with exposure to wave action, intertidal height, and colony structural species?*

Different species have different tolerances to biotic and abiotic factors, and as mentioned above, in addition, the intertidal zone is somewhat unique in that relatively great species biodiversity occurs over relatively small spatial distances. This means that the biodiversity in colonies in different locations may be quite variable, and needs to be characterised over a range of environmental conditions, biotic and abiotic.

- *How does colony biodiversity change with colony age?*

Older individuals are presumably usually larger than younger individuals in any location, and this means that colonies with older individuals may provide better protection for other species within the colony. Structural complexity, *i.e.*, the number of layers of mussels in the bed, increases with bed age, and community diversity increases correlatively. Also, the relative proximity of other colonies of either mussels or barnacles may influence local biodiversity.

- *Food chain implications of selective species harvests?*

Barnacles and mussels are filter-feeders, and while they each feed on different size particles, they likely exert relatively little influence on plankton concentrations in the nearshore area. However, as potential prey for other species, barnacles and mussels are likely important in intertidal food chain dynamics, and their substantial removal may affect, at least locally, the relative abundances of predator species.

- *Are there keystone species effects that should be investigated?*

Several authors have examined the role of keystone species in communities and assessed the extent of indirect effects of these keystone species in their respective communities. *Mytilus californianus* in particular has been identified as a keystone species in the exposed rocky intertidal.

2. Recommended Biological Data Collection Initiatives

Given the lack of sufficient information to address ecosystem effects associated with the harvest of intertidal structural species, studies are recommended to allow the acquisition of data needed to undertake a comprehensive ecosystem analysis of the effects of structural species harvest in the exposed bedrock intertidal. It should be noted that in the studies described below, while overall questions are framed around colonies of either sea mussels or goose barnacles, monitoring of the overall biological community is also required, along with specific documentation of the presence and spatial occurrences of mobile species, such as sea stars, crabs and other predators. Research proposed here includes documentation of characteristics in both undisturbed and perturbed sites. To allow unbiased investigation, a number of comparable randomly selected representative sites need to be identified, and then these in turn need to be randomly assigned to either undisturbed or perturbed protocols. Sufficient distance between sites needs to be established to eliminate treatment influences by actions in nearby sites. In all these studies, some, if not most, samples can be collected during goose barnacle biomass/abundance surveys, when all the animals (not just goose barnacles) can be enumerated and /or removed for lab analysis. Additional sampling may be required at non-goose barnacle sites. Studies are:

1. Characterisation of community structure and colony characteristics
   - Identification of macro-organisms found in association with goose barnacle and sea mussel colonies
     a) sampling should be done quarterly in representative harvest locations in a variety of exposures to wave action and at various heights above Chart Datum, with replication.
     b) parameters to be described would be species, life stages present, their relative sizes, associations with other species, and position in the food chain (trophic level)

   - Description of biotic structure in the ecosystem
     a) parameters to be described would include colony and “bare patch” sizes; colony, by species, and “bare patch” spatial distributions relative to intertidal height; sizes and

ages of individuals within colonies. Sampling should minimise colony destruction and cause as little damage as possible. Removal of animals for laboratory identification, enumeration and biological sampling will disturb the natural sites.

b) Study areas should be representative, randomly selected, and large enough to include at least 20 colonies (i.e. each of both barnacles and mussels).

2. Development of techniques, if necessary, for reliable estimation of barnacle and mussel ages

3. Documentation of colony and "bare patch" persistence and characteristics over time

- There is contradictory information in the literature as to the longevity and growth rates of barnacles, which may affect colony size and duration, and whether bare patches may get larger over time. These contradictions need to be clarified through new site-relevant studies
  - a) Undisturbed study areas should be the colony duration study sites and the goose barnacle biomass/abundance survey sites to prevent duplication. Monitoring annually would be similar to the protocol in (1), with documentation of relative sizes, spatial distributions and characteristics of colonies and bare patches. Recruitment and subsequent survival of species to both colonies and the areas between colonies would be documented quantitatively.
  - b) Monitoring of size and age characteristics of individuals within colonies should be undertaken, so that both individual growth rates and turnover rates of individuals within colonies can be determined. This will involve tagging or marking of individuals.
  - c) The biodiversity of colonies of different ages and sizes should be determined. This could be done by monitoring for biodiversity changes in a number of colonies over time, or if colony ages can be adequately determined, by monitoring of biodiversity in a number of colonies of different ages in a relatively short time period. Monitoring or biodiversity should include those areas immediately adjacent to the "structure" created by the colony, since this environment may also be influenced by the colony's presence.

4. Perturbation experiments to document the effects of colony removals

- The purpose of these studies is to evaluate the implications of having fisheries for structurally important species, so while the undisturbed ecosystem needs to be described, the effects of harvesting on the sustainability of the overall system also needs to be investigated. Perturbation experiments could include evaluation of possible "low-impact" and "code-of-conduct" fishing practices that may be proposed as part of Lauzier's studies (1999b) or developed by industry. Different levels of perturbation might be considered, but at the least, perturbation as would occur through commercial fishing should be one of the treatments. If fishing occurs in one area repetitively over a number of years, then this treatment, perhaps as well as a single year's fishing only, should also be considered.
  - a) Monitoring annually would be again similar to the protocol in (1), with documentation of relative sizes, spatial distributions and characteristics of colonies and bare patches. Recruitment and subsequent survival of species to both colonies and the areas between colonies would be documented quantitatively.

b) Monitoring of size and age characteristics of individuals within remaining colonies, if any, and new colonies as they become established should be undertaken, so that both individual growth rates and turnover rates of individuals within colonies can be determined. This might involve tagging or marking of individuals.

5. Documentation of annual variability in relative species abundances

- Identification of macro-organisms found in association with goose barnacle and sea mussel colonies
  a) sampling should be done quarterly in representative harvest locations in a variety of exposures to wave action and at various heights above Chart Datum, with replication.
  b) parameters to be described would be species, life stages present, their relative sizes, associations with other species, and position in the food chain (trophic level).

To ensure that study sites and harvest perturbations are realistic and appropriate, it is essential that collaboration with industry occur in the proposed research. Industry participants will be required both as advisors for some studies (e.g. appropriate site selection), and as active participants in others (harvest perturbation studies). However, such involvement should only occur under closely regulated conditions under the supervision of biologists, as it is important to avoid potential data bias and maintain data credibility. It is also recommended that First Nations groups be invited to participate, since many industry participants are natives and along the west coast of Vancouver Island, First Nations have competent biologists on staff. Collaboration between all parties also means that because all parties are involved throughout the studies, data obtained will be acceptable by all.

3. A Proposed Research Design

It would seem unwise to be too specific in describing required research, since the realities of field conditions and site differences will no doubt force modification of any proposed program. Nevertheless, we describe here a theoretical approach that we believe will provide the required data with which to make management decisions:

<u>General Study Site Locations</u>:

Although goose barnacles and sea mussels occur throughout BC, it is likely that exposed outer coast rocky intertidal species diversity differs somewhat between northern and southern BC. We therefore recommend study sites in both the Barkley Sound/Clayoquot Sound area and the Queen Charlottes or Central Coast.

Replication:

Replication is important, as fishers describe extreme differences in recovery rates between locations very close together. This will mean replication of experimental sites will be crucial, including replication within short distances.

1. *Characterisation of attached community structure*
   - These species are firmly attached to the substrate and cannot move as adults.
   - Five separated 3 to 5-m lengths of representative shoreline should be gridded over the intertidal height range in which sea mussels and goose barnacles are observed to occur into 100 cm^2 quadrats. A detailed map showing the precise locations and sizes of mussels and goose barnacle colonies should be drawn. In the upper and lower halves of this intertidal range being considered, 20-30 randomly selected quadrats should be sampled, with detailed recording of the species, number, and sizes of individuals present [note whether sampling was in a colony or not, and what portion (edge or centre) of the colony was sampled]. If at all possible, sampling should be non-destructive.

     However, some consumptive sampling of mussel beds will be required to characterise community structure in mature mussel beds. Documentation of a number of layers of live mussels and dead shells making up the community matrix and identity and abundance of "infaunal" organisms will require removal of samples, both to determine 3-D structure and to enumerate and identify what could potentially be a couple of hundred species. Differences in faunal components in northern and southern BC could be compared with literature from Washington State.

2. Characterisation of mobile community structure
These species are mobile over the study area.

a) Small infaunal, i.e. in "colony", species are unlikely to move up and down with the tide, and so unless armoured, will likely either hide in colonies, crevices or otherwise seek protection on the rock face. They will have to be searched for, and the species, their number and their sizes recorded in relation to distance away from mussel and goose barnacle colonies. Appropriate sampling methodologies, along with times of tide, day and year, etc., may have to be developed to allow them to be extracted from either colonies or crevices.
b) Larger mobile species, such as sea stars and crabs, which occur around and on the colonies, but not in them, may need to be visually sampled over a larger designated area, as they are perhaps unlikely to be captured with limited randomised sampling.

3. Characterisation of patch dynamics
These study sites are the controls for the overall study – sites will not be impacted by research, and research will focus on measuring and recording the fates of bare patches and colonies of different

species. Sites should be representative of the other sites, and numerous enough to give adequate replication.

4. Colony perturbation experiments
Information is needed from fishery harvest data as to the harvesting impacts and characteristics from commercial fishers. What size bare patches are likely to be created by harvesting, and how are these patches spatially related? This information will determine both the nature of the perturbations to be implemented (scale of bare patch size can affect patch dynamics and recovery rates) and the overall sizes of these study sites. Industry and First Nation fisher participation may be most relevant and cost-effective here, as the scale and nature of impact needs to be as realistic to commercial fishery impacts as possible. Another factor is assessing the significant spatial and temporal scales for the mussel-goose barnacle communities on the outer coast. These community interactions are dynamic and dominated by biological processes at small scales but physical processes at larger scales. Further, there are important differences depending on the frequency of disturbances. Identifying these scales might go faster by comparing undisturbed and previously harvested locations now, if they can be identified. Although the complete previous history of such locations may not be known (nor would the past history of the site be known with a designed new experiment), results from such an analysis might be used to ballpark answers to the scale problem, and results could be obtained relatively quickly.

Priority Concerns

For the development of the goose barnacle fishery to follow the phased approach described in the Pacific Region Policy for New and Developing Fisheries, the following summarised recommendations were presented by Lauzier (1999b):

1) Initiate a broad-brush survey/inventory of goose barnacle populations in wide geographic areas (e.g. West Coast of Vancouver Island).
2) Selected goose barnacle sites within smaller geographic areas (e.g. Clayoquot Sound) should be identified, measured and geo-referenced in order to provide baseline information for the selection and establishment of control sites and experimental harvest sites within the smaller geographic areas. Experimental fishing areas should be established to test alternative harvesting practices.
3) Harvest techniques, including the development of new approaches, if considered necessary, that are more selective and result in a higher proportion of high quality product should be evaluated.
4) A code of responsible harvesting practices should be developed and training should be provided to all harvesters once a code has been developed and approved.

These studies would be initiated in the spring, 2000, and while some collecting long-term growth and mortality data will extend over a number of years, it was proposed that an experimental fishery could be initiated in the spring, 2000, which would then be monitored to determine fishery effects. This is also an appropriate time scale for the ecological studies discussed in this paper. The goose barnacle study sites identified in the stock assessment phase of the study should also be appropriate for the ecological studies, and so both projects should “piggy-back” on each other. The overall time scale for the proposed studies may be a relatively long-term undertaking, since this is DFO's first comprehensive attempt to undertake such a study. However, this should not prevent an experimental fishery from being conducted while the studies are underway. In fact, such a situation would be desirable, since it would allow comparison between control (no fishery) sites and experimentally harvested sites. Some results will be available the first year, but documentation of annual variability and the effects of fishing on ecosystem structure may take 5-10 years to show conclusive results.

Recommendations

1. Longer-term perturbation experiments that include experimental harvesting in the exposed rocky intertidal zone should be designed and initiated that will allow an evaluation of harvesting impacts on the ecosystem. The habitat, bio-diversity and spatial distributions of key macro-species in the study areas should be described along with other ecosystem characteristics.

2. The participation of committed stakeholders and resource managers in planning the implementation of these recommendations, as well as those in the stock assessment surveys and experiments, is highly recommended to integrate their experience and traditional knowledge with a scientifically based assessment and management plan.

Bibliography:

Addressi, L. 1994. Human disturbance and long-term changes on a rocky intertidal community. Ecological Applications. 4(4): 786-797.

Arima, E.Y. 1983. The west coast people. B.C. Prov. Mus. Spec. Publ. 6.

Austin, W.C. 1987. A feasibility study for the commercial harvesting of the goose barnacle *Pollicipes polymerus*. Final Report, Contract to Dept. Fish. Oceans, Pacific Region, Nanaimo, B.C.: 171 pp.

Austin, W.C. 1992. Goose Barnacle Survey. Final Report, Contract PPS 1-073 to Dept. Fish. Oceans, Pacific Region, Nanaimo, B.C.: 24 pp.

Barnes, H. and E.S. Reese. 1960. The behaviour of the stalked intertidal barnacle *Pollicipes polymerus,* J.B. Sowerby, with special reference to its ecology and distribution. J. Animal Ecol. 29: 169-185.

Berlow, E.L. 1997. From canalization to contingency: Historical Effects in a successional rocky intertidal community. Ecol. Monogr. 67(4): 435-460.

Berlow, E.L. and S.A. Navarrete. 1997. Spatial and temporal variation in rocky intertidal community organization: Lessons from repeating field experiments. J. Exp. Mar. Biol. Ecol. 214: 195-229.

Bernard, F.R. 1988. Potential fishery for the gooseneck barnacle *Pollicipes polymerus* (Sowerby, 1833) in British Columbia. Fish. Res. 6: 286-298.

Bourne, N.F. 1997. Molluscan fisheries of British Columbia. NOAA Tech. Rep. NMFS 128: 115-130.

Brosnan, D.M. and L.L. Crumrine. 1994. Effects of human trampling on marine rocky shore communities. J. Exp. Mar. Biol. Ecol. 177: 79-97.

Burley, D.V. 1989. Senewélets: culture history of the Nanaimo Coast Salish and the False Narrows midden. Royal B.C. Mus. Mem. 2.

Carefoot, T. 1977. Pacific Seashores. A Guide to Intertidal Ecology. J.J. Douglas Ltd., Vancouver, 208 pp.

Chan, G.L. 1973. Subtidal mussel beds in Baja California, with a new record size for *Mytilus californianus*. Veliger 16: 239-240.

Coe, W.R. and D.L. Fox. 1942. Biology of the California sea-mussel (*Mytilus californianus*). I. Influence of temperature, food supply, sex and age in the rate of growth. J. Exp. Zool. 99(1): 1-14.

Coe, W.R. and D.L. Fox. 1944. Biology of the California sea-mussel (*Mytilus californianus*). III. Environmental conditions and rate of growth. Biol. Bull. (Woods Hole) 7(1): 59-72.

Dayton, P.K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. 41(4): 351-389.

Dehnel, P.A. 1956. Growth rates in latitudinally and vertically separated populations of *Mytilus californianus*. Biol. Bull. 110: 43-53.

Ditman, D. and C. Robles. 1991. Effect of algal epiphytes on the mussel *Mytilus californianus*. Ecology 72(1): 286-296.

Duran, L.R., J.C. Castilla, and D. Oliva. 1987. Intensity of human predation on rocky shores at Las Cruces in Central Chile. Environmental Conservation. 14:143-149.

Ellis, D.W. and L. Swan. 1981. Teachings of the Tides: Uses of Marine Invertebrates by the Manhousat People. Theytus Books, Nanaimo. 118 p.

Ellis, D.W. and S. Wilson. 1981. The knowledge and usage of marine invertebrates by the Skidegate Haida people of the Queen Charlotte Islands. Queen Charlotte Islands Museum Society Monograph 1. 40 p.

Elvin, D.W. and J.J. Gonor. 1979. The thermal regime of an intertidal *Mytilus californianus* Conrad population on the central Oregon coast. J. Exper. Mar. Biol. Ecol. 39(3): 265-279.

Feder, H,M, 1959. The food of the starfish, *Piaster ochraceus*, along the Californian coast. Ecology 40: 721-724.

Fox, D.L. and W.R. Coe. 1943. Biology of the California sea-mussel (*Mytilus californianus*). II. Nutrition, metabolism, growth and calcium deposition. J. Exp. Zool. 93: 205-249.

Gillespie, G.E. 1999. Stock assessment and management frameworks for the proposed fishery for sea mussels (*Mytilus californianus*) in British Columbia. Can. Stock Assess. Secret. Res. Doc. 99/116. 43 p.

Harger, J.R.E. 1968. The role of behavioural traits in influencing the distribution of two species of sea mussel, *Mytilus edulis* and *M. californianus*. Veliger 11(1): 45-49.

Harger, J.R.E. 1970. Comparison among growth characteristics of two species of sea mussels, *Mytilus edulis* and *Mytilus californianus*. Veliger 13(1): 44-56.

Harger, J.R.E. 1972. Competitive coexistence: maintenance of interacting associations of the sea mussels *Mytilus edulis* and *Mytilus californianus*. Veliger 14(4): 387-410.

Hewatt, W.G. 1935. Ecological succession in the *Mytilus californianus* habitat as observed in Monterey Bay, California. Ecology 16: 2244-2251.

Hewatt, W.G. 1937. Ecological studies on selected intertidal communities of Monterey Bay, California. Amer. Midl. Naturalist 18(2): 161-206.

Hoffman, D.L. 1989. Settlement and recruitment patterns of a pedunculate barnacle, *Pollicipes polymerus* Sowerby, of La Jolla, California. J. Exp. Mar. Biol. 125: 83-98.

Jamieson, G.S. 1989. Growth, reproduction and longevity of blue mussels (*Mytilus edulis*): implications to northeastern Pacific mussel culture. World Aquacult. Review 20: 94-100.

Keough, M.J. and G.P. Quinn. 1998. Effects of periodic disturbances from trampling on rocky intertidal algal beds. Ecological Applications 8(1): 141-161.

Lauzier, R.B. 1999a. A review of the biology and fisheries of the goose barnacle (*Pollicipes polymerus* Sowerby, 1833). Can. Stock Assess. Secret. Res. Doc. 99/111. 30 p.

Lauzier, R.B. 1999b. Framework for goose barnacle (*Pollicipes polymerus* Sowerby, 1833) fishery in waters off the West Coast of Canada. PSARC Working Paper Document I99-18.

Levings, C.D. and G.S. Jamieson. 1999. Evaluation of criteria for creating MPAs in the Pacific Region: A proposed semi-quantitative scheme. PSARC Working Paper Document H99-5.

Lewis, C.A. and F-S. Chia. 1981. Growth, fecundity, and reproductive biology in the pedunculate cirripede *Pollicipes polymerus* at San Juan Island, Washington. Can. J. Zool. 59:893-901.

Lindberg, D.R., J.A Estes, and K.I. Warheit. 1998. Human influences on trophic cascades along rocky shores. Ecological Applications 8(3): 880-890.

Marsh, C.P. 1986. Rocky intertidal community organization: the impact of avian predators on mussel recruitment. Ecology 67(3): 771-786.

Meese, R.J. 1993. Effects of predation on birds on goose-neck barnacle *Pollicipes polymerus* Sowerby distribution and abundance. J. Exp. Mar. Biol. Ecol. 166: 47-64.

Menge, B.A., E.L. Berlow, C.A. Blanchette, S.A. Navarrete, and S. B. Yamada. 1994. The keystone species concept: variation in strength interaction in a rocky intertidal habitat. Ecol. Monogr. 64(3): 249-286.

Menge, B.A. 1995. Indirect effects in marine rocky intertidal interaction webs:Patterns and importance. Ecol. Monogr. 65(1): 21-74.

Newman, W.A. and D.P. Abbott. 1980. Cirripedia: the barnacles: *In* R.H. Norris, D.P. Abbott, and E.C. Haderlie [eds], Intertidal Invertebrates of California, Standford University Press, Standford, California

Paine, R.T. 1966. Food web complexity and species diversity. Am. Natur. 100: 65-75.

Paine, R.T. 1974. Intertidal community structure. Experimental studies on the relationship between a dominant competitor and its principal predator. Oecologia 15: 93-120.

Paine, R.T. 1976a. Size-limited predation: an observational and experimental approach with the *Mytilus-Pisaster* interaction. Ecology 57: 858-873.

Paine, R.T. 1976b. Biological observations on a subtidal *Mytilus californianus* bed. Veliger 19(2): 125-130.

Paine, R.T. 1980. Food webs: linkage, interaction strength and community infrastructure. J. Animal Ecol. 49:667-685.

Paine, R.T. 1989. On commercial exploitation of the sea mussel, *Mytilus californianus*. Northwest Environ. J. 5(1): 89-97

Paine, R.T. and S.A. Levin. 1981. Intertidal landscapes: disturbance and the dynamics of pattern. Ecol. Monogr. 51(2): 145-178.

Peterson, J.H. 1984a. Establishment of mussel beds: attachment behaviour and distribution of recently settled mussels (*Mytilus californianus*). Veliger 27(1): 7-13.

Peterson, J.H. 1984b. Larval settlement behaviour in competing species: *Mytilus californianus* Conrad and *M. edulis* L. J. Exper. Mar. Biol. Ecol. 82(2-3): 147-159.

Petraitis, P.S. 1978. Distributional patterns of juvenile *Mytilus edulis* and *Mytilus californianus*. Veliger 21(2): 288-292.

Povey, A, and M.J. Keough. 1991. Effects of trampling on plant and animal populations on rocky shores. Oikos 61: 355-368.

Ricketts, E.F. and J. Calvin. 1968. Between Pacific Tides. 4th ed.; revised by J.W. Hedgepeth. Standford University Press, Standford, California.

Robles, C., R. Sherwood-Stevens and M. Alvarado. 1995. Responses of a key intertidal predator to varying recruitment of its prey. Ecology 76(2): 565-579.

Scagel, R.F. 1970. Benthic algae of Bowie Seamount. Syesis 3: 15-16.

Schiel, D.R. and D.I. Taylor. 1999. Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. J. Exp. Mar. Biol. Ecol. 235: 213-235.

Seed, R. and T.H. Suchanek. 1992. Population and community ecology of *Mytilus*. p. 87-169. *In*: E.M. Gosling [ed.]. The Mussel *Mytilus*: Ecology, Physiology, Genetics, Culture. Elsevier Scientific Publ. Co., Amsterdam.

Shaw, W.N., T.J. Hassier and D.P. Moran. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)-- California sea mussel and bay mussel. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.84) U.S. Army Corps of Engineers, TR EL-82-4. 16 p.

Sousa, W.P. 1984. Intertidal mosaics: patch size, propagule availability, and spatially variable patterns of succession. Ecology 65: 1918-1935.

Stocker, M. and I. Winther. 1999. Report of the PSARC Invertebrate Subcommittee meeting January 25-28, 1999. Can. Stock Assess. Proc. Ser. 99/01. 29 p.

Suchanek, T.H. 1979. The *Mytilus californianus* community: studies on the composition, structure, organization and dynamics of a mussel bed. Ph.D. Thesis, Univ. of Washington, Seattle. 286 p.

Suchanek, T.H. 1981. The role of disturbance in the evolution of life history strategies in the intertidal mussels *Mytilus edulis* and *Mytilus californianus*. Oecologia 50(2): 143-151.

Suchanek, T.H. 1985. Mussels and their role in structuring rocky shore communities. P. 70-90. *In*: P.G. Moore and R. Seed [eds.]. The Ecology of Rocky Coasts. Hodder and Stoughton, Ltd., London.

Suchanek, T.H. 1992. Extreme biodiversity in the marine environment: mussel bed communities of *Mytilus californianus*. Northwest Environ. J. 8(1): 150-152.

Suchanek, T.H. 1994. Temperate coastal marine communities: biodiversity and threats. Amer. Zool. 34: 100-114.

Vermeer, K. 1982. Comparison of the diet of the glaucous-winged gull on the east and west coasts of Vancouver Island. The Murrelet 63 (3): 80-85

Whedon, W.F. 1936. Spawning habits of the mussel *Mytilus californianus* with notes on the possible relation to mussel poisoning. Univ. Calif. Publ. Zool. 41: 35-44.

Witman, J.D. and T.H. Suchanek. 1984. Mussels in flow: drag and dislodgment by epizoans. Mar. Ecol. Prog. Ser. 16: 259-268.

Wootton, T.J. 1997. Estimates and tests of per capita interaction strength: Diet, abundance, and impact of intertidally foraging birds. Ecol. Mono. 67(1): 45-64

Wootton, T.J. 1994. Predicting direct and indirect effects: An integrated approach using experiments and path analysis. Ecology 75(1): 151-165.

Wootton, T.J. 1993. Size-dependent competition: Effects on the dynamics vs. the end point of mussel bed succession. Ecology 74(1): 193-206

Wootton, T.J. 1992. Indirect effects, prey susceptibility, and habitat selection: impacts of birds on limpets and algae. Ecology (73(3): 981-991.

Yamada, S.B. and J.B. Dunham. 1989. *Mytilus californianus*, a new aquaculture species? Aquaculture 81: 275-284.

Yamada, S.B. and E.E. Peters. 1988. Harvest management and growth and condition of submarket-size sea mussels, *Mytilus californianus*. Aquacult. 74(3-4): 293-299.

Young, R.T. 1942. Spawning season of the California mussel *Mytilus californianus*. Ecology 3: 490-492

Zelder, J. 1978. Public use effects in the Cabrillo National Monument intertidal zone. Project report for the U.S. Department of the Interior, National Park Service. Cabrillo National Monument, Point Loma, San Diego, California, U.S.A.

Table 1: Historical Effort of the Goose Barnacle Fishery in British Columbia.

Year	#of Licences	Fishing Days[1]
1985	9	145
1986	25	77
1987	221	789
1988	467	1596
1989	130 Z-6	713
1990	137 Z-6	2278
1991	131 Z-6	3070
1992	125 Z-6	1878
1993	105 Z-6	2049
1994	114 Z-6	1482
1995	65 Z-6	321
1996	56 Z-6	574
1997	49 Z-6	427
1998	39 Z-6	215

[1]Reported

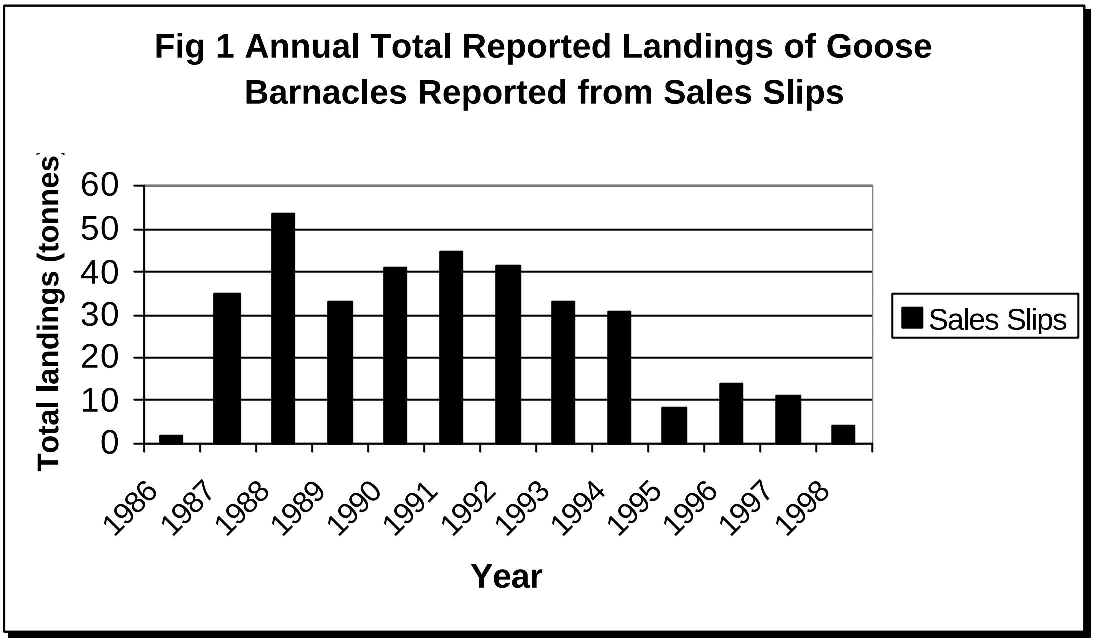
Fig 1 Annual Total Reported Landings of Goose Barnacles Reported from Sales Slips
Total landings (tonnes)
60
50
40
30
20
10
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
Sales Slips

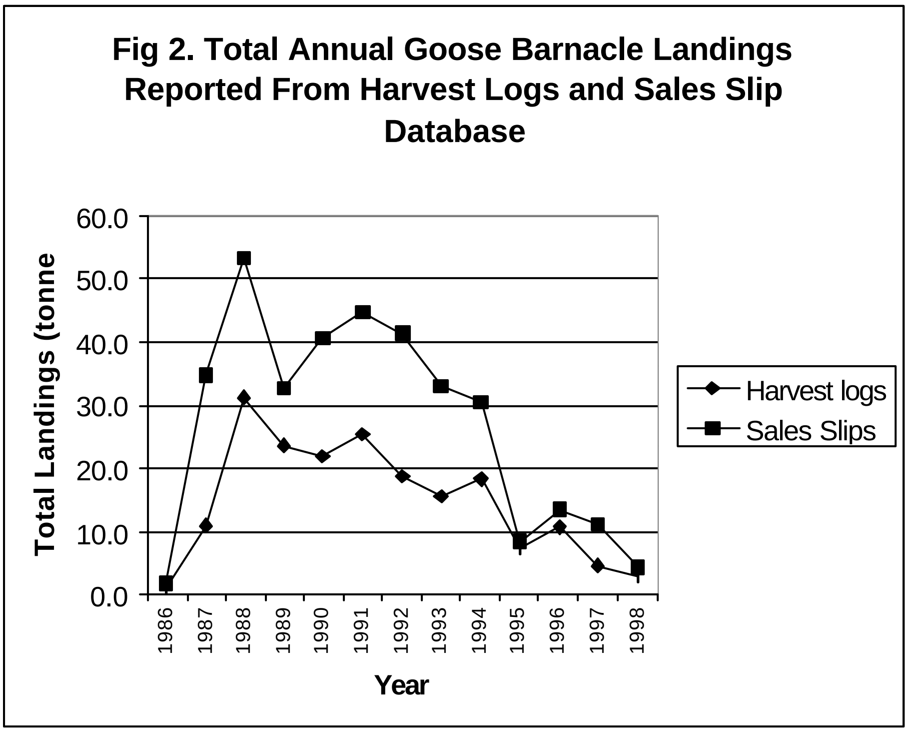
Fig 2. Total Annual Goose Barnacle Landings Reported From Harvest Logs and Sales Slip Database
Total Landings (tonne
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
Harvest logs
Sales Slips