Fisheries and Oceans Canada | Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/163

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/163

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

Ne pas citer sans
autorisation des auteurs[1]

A Review of the Biology and Fisheries for Purple Sea Urchin (*Strongylocentrotus purpuratus,* Stimpson, 1857) and Discussion of the Assessment Needs for a Proposed Fishery

G. Workman

Stock Assessment Division
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, V9R 5K6

[1] This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

[1] La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au secrétariat.

ISSN 1480-4883
Ottawa, 1999

Canada

Abstract

In accordance with the phased approach to providing scientific advice for new and developing fisheries, the following paper has been prepared as the "Phase 0: Review of existing information" assessment for the purple sea urchin *Strongylocentrotus purpuratus*. This paper consists of a review of the relevant literature on the biology of *S. purpuratus*, and describes urchin fisheries on the west coast of North America. Relevant management measures, and their data requirements, that should be applied to any fishery for purple sea urchins are discussed. Interest was first expressed in starting a fishery for this species in the late 1980s, a small experimental fishery ran between 1989 and 1992, when concerns over compliance with the terms of the experimental harvest permit and local depletion lead to a closure of the fishery. Since 1992, nine proponents have requested a re-opening of the fishery.

Intertidal *S. purpuratus* have been studied extensively in Oregon and in California. This species is characterized by long life, greater than 50 years, patchy distribution, slow and variable growth, low and periodic recruitment, is sedentary and displays density dependant spawning success (Allee effect). The above characteristics are indicative of a species susceptible to over-exploitation, which in turn dictates a very cautious approach to fisheries development.

Small fisheries for S. purpuratus exist in Oregon and California. The fisheries for purple sea urchin are of limited success because of this urchin's small size, variable gonad quality and the harsh conditions under which it must be harvested. Other urchin fisheries on the west coast of North America include *S. franciscanus*, the giant red sea urchin, which is harvested from South-east Alaska to Baja California, Mexico and *S. droebachiensis,* the green sea urchin, which is harvested from Kodiak, Alaska to Washington State. Red sea urchin fisheries in Oregon and Northern California have collapsed under excessive fishing pressure, the green sea urchin fishery in British Columbia likewise peaked and crashed. These are examples of "Boom and Bust" fisheries where rapid development of a commercial fishery decimates the virgin biomass prior to assessment of the resource.

Suggested management measures include quotas, size limits, seasonal closures, a rotational fishery and limited entry. The data requirement for the first of these measures could be met by an extensive survey and bio-sampling program, designed to ascertain the abundance, and life history parameters of purple urchins and the appropriate spatial scale on which to implement these management actions.

Résumé

Conformément à la démarche par étapes pour la prestation d'avis scientifiques visant des pêches nouvelles ou en développement, le document ci-après a été préparé en tant que « Étape 0 : Examen des renseignements actuels » – à titre d'évaluation pour l'oursin violet *Strongylocentrotus purpuratus*. On y trouve un examen des publications pertinentes sur la biologie de *S. purpuratus* ainsi qu'une description de sa pêche sur la côte ouest de l'Amérique du Nord. On y traite aussi des mesures de gestion, et des besoins de données, qui devraient s'appliquer à toute pêche de l'oursin violet. Un intérêt pour cette pêche a tout d'abord été exprimé à la fin des années 1980 et une petite pêche expérimentale a été pratiquée de 1989 à 1992, date à laquelle des préoccupations relatives au respect des conditions du permis de récolte expérimentale et à un appauvrissement local ont donné lieu à la fermeture de la pêche. Depuis 1992, neuf propositions de réouverture de cette pêche ont été faites.

Les *S. purpuratus* de la zone intertidale ont fait l'objet d'une étude approfondie en Oregon et en Californie. Cette espèce se caractérise par sa longévité, qui est supérieure à 50 ans, une répartition inégale, une croissance faible et variable, un recrutement limité et périodique, une vie sédentaire et un succès de la reproduction fonction de la densité (effet Allee). Ces caractéristiques sont celles d'une espèce susceptible de surexploitation et obligent à une démarche très prudente au moment de la mise en valeur d'une pêche.

Il existe de petites pêches de *S. purpuratus* en Oregon et en Californie. Le succès de la pêche de l'oursin violet est limité par la petite taille de ces oursins, la qualité variable des gonades et les conditions difficiles dans lesquelles il est récolté. Les autres espèces d'oursins de la côte ouest de l'Amérique du Nord qui sont récoltées sont le *S. franciscanus*, l'oursin rouge géant, qui est récolté du sud-est de l'Alaska à la Basse-Californie, au Mexique, et le *S. droebachiensis,* l'oursin vert, qui est récolté de l'île Kodiak, en Alaska, jusqu'à l'État du Washington. La pêche de l'oursin rouge de l'Oregon et du nord de la Californie s'est effondrée suite à une pression de pêche excessive et celle de l'oursin vert faite en Colombie-Britannique a atteint, elle aussi, un pic avant de s'effondrer. Il s'agit là d'exemples de pêches à rendement élevé suivi d'un effondrement où un développement rapide de la pêche commerciale décime la biomasse vierge avant qu'il y ait eu évaluation de la ressource.

On compte, parmi les mesures de gestion proposées, l'imposition de quotas, de limites de tailles, de saisons, de pêches en rotation et de participation limitée. Les données nécessaires à l'application de la première de ces mesures peuvent être obtenues par un relevé de grande envergure et un programme de prélèvements biologiques conçus dans le but de vérifier l'abondance et les paramètres du cycle vital des oursins violets, de même que l'échelle spatiale appropriée où doivent être appliquées ces mesures de gestion.

Table of Contents

List Of Tables

List Of figures

Policy on New Fisheries

The Department of Fisheries and Oceans (DFO) placed a moratorium on new invertebrate fisheries in 1992. At the time it was realized the department lacked the resources to adequately assess and manage additional fisheries. Although it was acknowledged that unfished or underutilized species exist off the coast of British Columbia little could be done to address the question of new fisheries until policy and guidelines governing their development where developed. A memorandum of understanding (MOU) between the DFO and the provincial Ministry of Agriculture, Fisheries and Food on Fisheries and Seafood Diversification was signed in December 1995. Policy and guidelines for the development of new fisheries were developed in 1998, (Anon, 1998) as follows:

- **New fisheries will be developed that ensure resource sustainability and conservation.** A precautionary approach for providing the biological basis for managing new fisheries and ensuring resource sustainability is outlined in "A framework for providing scientific advice for the management and development of new and developing invertebrate fisheries" (Perry et al., 1999).

- **Aboriginal rights will be respected and first Nation's involvement encouraged**. Aboriginal people have the right to fish for food, societal and ceremonial purposes, a right second only to conservation.

- **Opportunities will be provided for an economically viable fishery to develop**. Participants will be given the opportunity to assess the viability of a new fishery.

- **Participants in new fisheries will finance the costs of managing the fishery**. An agreement must be reached wherein the proponents bear costs of management, enforcement and assessment of the fishery.

- **An open, fair and consistent process for participants will be provided**. The process must be open to all potential participant and the roles of governmental agencies clearly defined.

- **Once a fishery is established commercially, participants will provide a return to the public for access to a public resource**. The participants will pay license fees and potentially other management and assessment fees.

- **Initial participants will be provided the opportunity for further participation in the development of the fishery**. Early participants will be given priority to participate in further resource development.

The framework described by Perry et al. (1999) explicitly endorses the precautionary approach to fisheries development, management and research. Essentially the framework calls for a phased approach wherein:

- **Phase 0: Collection of existing information** is the collection and review of all relevant literature on the proposed target species and a review of any existing data. This review should cover other species with overlapping distributions, similar life history or a fishery similar to that proposed for the new species. Information gaps need to be identified and alternative management approaches considered.
- **Phase 1: Collection of new information** to address the needs identified in the Phase 0. These needs may be addressed through surveys, test fisheries or laboratory analysis. In general the key information requirements concern the population abundance, spatial distribution (discrete or continuos), size and age structure of the population and an assessment of life history parameters such as growth and mortality.
- **Phase 2: Fishing for commerce** is the initiation of a commercial fishery with ongoing monitoring and evaluation of the management strategies selected. The monitoring should include a program of biological sampling to assess the population response to harvest, a harvest log program to monitor removals and a catch validation program to monitor compliance.

Introduction

A fishery for the purple sea urchin, *Strongylocentrotus purpuratus*, has been proposed. This document has been prepared as the "Phase 0: Collection of existing Information" assessment. Interest in this species was first expressed in the late 1980s, when the red and green sea urchin fisheries were rapidly expanding. A small experimental fishery ran between 1989 and 1992. Since the fishery was closed in 1992, nine proponents including the BC Purple Urchin Association and the West Coast Research Initiatives Group have expressed interest in starting a commercial fishery for purple sea urchins. A strategy document for the development of a purple sea urchin fishery in BC was prepared for the Purple Sea Urchin Association and the BC Ministry of Agriculture, Fisheries and Food in 1995 (Krause, 1995). Limited resources prevented further development of purple sea urchins as a fishery until the fall of 1998 when funds became available through fisheries diversification to hire assessment and management staff to oversee the review of new and developing invertebrate fisheries.

Fisheries for sea urchins produce roe, (both male and female gonads) as the only product. The roe is marketed, mostly in Japan, as "uni" and used in sushi restaurants. The preferred product is fresh but markets exist for frozen, canned, salted and fermented products (Kramer and Nordin, 1979). Domestic utilization of sea urchins as food has been low until the recent upswing in the popularity of Asian foods. The remains of sea urchins have been found in the middens of early coastal native Americans indicating their utilization as a food source.

There is a large body of literature detailing the growth (Ebert, 1967, 1968, 1982; Russell, 1987; Lewis et al. 1990; Swan, 1961), physiology (Boolootian, 1966), life history and recruitment (Ebert, 1983; Cameron and Schroeter, 1980), trophic relationships (Duggins, 1983; Tegner and Dayton, 1981), toxicology (Baldwin et al,, 1992), and reproduction (Gonor, 1972, 1973a, 1973b). However there is little information on the biology of *S. purpuratus* from British Columbia (Kramer and Nordin 1975; Russell, 1987; Campbell, 1992).

In this document the biology of *S. purpuratus* and its relatives will be discussed. As well, the urchin fisheries on the West Coast of North America will be reviewed. Particular attention will be paid to the commercial fisheries for purple sea urchin, which have taken place in California and Oregon States as well as the experimental permit fishery which occurred in British Columbia between 1989 and 1992. Some data on the size composition and population density of purple sea urchins was collected during the experimental fishery, these data will be reviewed as part of this assessment.

Phase 0 assessments have been authored for new species and previously unassessed species including California mussel, *Mytilus californianus* (Gillespie, 1999), the goose barnacle, *Pollicipes polymerus* (Lauzier, 1999), octopus (Gillespie et al. 1998), horse clams, *Tresus capax* and *Tresus nuttallii* (Lauzier et al. 1998), oceanic squid, *Ommastrephes bartrami, Onychoteuthis borealijaponica, Gonatopsis borealis* and *Berryteuthis magister* (Gillespie, 1997), milky venus clam, *Compsomyax subdiaphana* (Lauzier, 1997), and grooved tanner crab, *Chionoecetes tanneri* (Phillips and Lauzier, 1997). In each, the common information that is lacking is an initial estimate of abundance and data on longevity, recruitment and mortality of the target species. Research needs are identified and alternative management options are discussed.

Review of Sea Urchin Biology

Taxonomy and Identification (After Morris et al. 1980):

Phylum	Echinodermata
Class	Echinoidea
Order	Echinoida
Family	Strongylocentrotidae
Genus	Strongylocentrotus
Species	Purpuratus

The test diameter (TD) of *Strongylocentrotus purpuratus*, the maximum diameter of the urchin excluding the spines, is commonly 50 mm, but individuals as large as 104 mm (Kramer and Nordin, 1975) have been recorded. Spines rarely exceed 25 mm in length. Body and spines are typically bright purple but can occasionally be pale green especially in juveniles. Test shape (relative test diameter compared to test height) varies from low to high and from circular to pentagonal in outline. Ambulacral pore pairs are arranged in curving arcs of eight on the upper side of test, primary interambulacral tubercles occupying much less than half of the area of the individual plates. Secondary tubercles numerous and form quite distinct rows in all columns (Morris et al. 1980).

Anatomy of the Sea Urchin

The following general description for Strongylocentrotidae is from Mottet (1976). Sea urchins are related to sea stars, sea cucumbers, sea lilies, and sand dollars. Like sea stars, urchins display almost radial symmetry which is most visible in the cleaned shell or test (Figure 1). The five areas of the test that possess tube feet are called ambulacral areas, between them are the interambulacral areas. Looking at the test from the top (aboral) or bottom (oral) side, one can see double rows of tiny holes (pore arcs) through which tube feet are extended or withdrawn. Tube feet are equipped with suction disks which are used to either firmly anchor the animal in place or for locomotion. The tube feet serve other functions as well: they are sensitive to chemicals and to touch; they absorb oxygen or dissolved organics; they catch drifting algae for food; and they keep the test clean. In addition to tube feet, urchins have pedicellariae which are similar to tube feet except that the tips are equipped with tiny pinchers. The pedicellariae are used to keep the shell clean, hold objects over the urchin for shade or camouflage, or to capture drift algae and pass it to the mouth. Purple urchins in small tide pools on the west coast of Vancouver Island will almost completely cover themselves with large pieces of shell and drift algae either as camouflage or for shade.

Marking the base of each spine is a tubercle, which forms a neat ball and socket joint and allows the spine to be moved in any direction. The spines can be used for crawling, and fast-moving urchins are more likely to use the spines than the tube feet for locomotion. The primary function of spines for all sea urchins is to discourage predation. Spines are on both the ambulacral and interambulacral areas of the test, but the ambulacral spines are shorter. The hard test, which protects the soft parts of the urchin, is made of many small skeletal elements called plates, each plate is composed of a single calcite crystal (Figure 2A).

The internal organs include the teeth, esophagus, gut, intestine and gonads (Fig. 2). The five teeth, which are visible externally and are part of Aristotle's lantern (Fig. 3), chew the food, which then moves through the oesophagus, stomach, and intestine. When the food enters the intestine, it is formed into round pellets; these pellets are later excreted at the aboral side of the test through the anus. Depending on the time of year, the largest organs are the five gonads. Each gonad is centred in one of the five interambulacral areas. Surrounding the teeth is the peristomal membrane. This is the only place where the sea urchin is not protected by the hard test and is often used by predators to gain access to the internal organs.

Urchins of BC, Description and Distribution

Austin (1985) lists 4 other species from the family Strongylocentrodidae from BC waters. *Allocentrotus fragilis* is found on the west coast of North America from Vancouver Island south to Baja California at depths of 50 to 1150 m (McCauley and Carey, 1967). The prevailing coloration of the living animal is orange-pink; cleaned tests are a pale orange-pink and are extremely fragile (Kozloff, 1974). Their preferred substrates are fine sands and clayey silts (McCauley and Carey, 1967). In North America, *Strongylocentrotrus pallidus* is found from the Arctic Ocean as far south as Oregon on the west coast and Massachusetts Bay on the east coast, in the western Pacific south to Japan and Korea. This species is always subtidal from 5 to 1600 m, usually at depths greater than 50 m. It is found on bedrock, clay, gravel, or broken shell (Mottet, 1976). The prevailing coloration of the spines is whitish, although some, especially near the centre of the aboral surface, may be greenish. Tube feet are usually about the same color as the spines (rarely much darker), and the diameter of the test rarely exceeds 6 cm (Kozloff, 1974). The red sea urchin, *Strongylocentrotus franciscanus*, is the largest urchin occurring in BC waters. It lives at shallow depths, typically from 5-10 meters, although it may also be found intertidaly or at depths up to 125 meters. It is usually found on rocky substrates in zones of brown seaweed, where currents are moderate to swift (Mottet, 1976). It is distributed from Baja California northward to Alaska, and across the Aleutian Islands (McCauley and Carey, 1967). Prevailing coloration is usually bright red, reddish-purple, or maroon, although the larger spines of lighter specimens may be rose and the smaller spines almost white. Test diameter up to 19 cm (Bureau, 1996) with spines up to 7 cm long in larger individuals (Kozloff, 1974). The green sea urchin *Strongylocentrotus droebachiensis* is circumpolar. In the eastern Pacific, it is found as far north as Point Barrow, Alaska and southward to Washington state (Mottet, 1976). It occurs in the Aleutian Islands and westward to Kamchatka, Korea, and Hokkaido, Japan. In the north Atlantic it may be found on the east coast of the U.S. and Canada, and in Greenland, Iceland, and northern Europe. It lives at depths up to 130 m, but more commonly from 12 m to the mean low tide mark. It prefers rocky, gravel, or shell substrates, but it may also be found on sand or muddy bottoms (Mottet, 1976, Scott, 1902). The prevailing coloration of the spines is pale greenish, tube feet are darker than the spines and usually purple with test diameters up to 8 cm (Kozloff, 1974).

Distribution and Habitat of S. purpuratus

Strongylocentrotus purpuratus is the common intertidal sea urchin of exposed and semi-protected rocky habitats on the west coast of North America. It is found on almost every rocky outcrop along the west coast from Torch Bay, Alaska (Duggins, 1983) to Isla Cedros, Baja California, Mexico (Ricketts and Calvin, 1939). Though most common inter-tidally, specimens have been collected from as deep as 160 m (Morris et al. 1980). It is common in the lower intertidal, typically in areas of moderate to strong wave action or tidal surge. As an adaptation to the pounding surf on exposed coastlines this species is often found in rounded burrows or depressions in the rock which it may enlarge with its teeth and spines as it grows. As a result, some urchins become trapped in burrows with openings too small to permit the animal to escape. Purple urchins have been reported from boulder fields, tide pools in eelgrass beds, and exposed sandstone flats.

Gonor (1972) found densities >100 urchins/m^2 common along the Oregon Coast. These aggregations were predominantly composed of individuals 50 – 60 mm test diameter. Ebert (1968) found densities up to 200 urchins per m^2 in tide pools at Sunset Bay, Oregon; densities as high as 300 urchins per m^2 are not uncommon (Dayton, 1975). Intertidal *S. purpuratus* do not undertake significant seasonal migrations, moving no more than tens or hundreds of meters in a lifetime (Ebert et al. 1994), subtidal populations may however undertake modest foraging or spawning migrations.

Commercial urchin fishers in BC report they are relatively common although occurring only in the most exposed areas usually in discrete patches. Campbell (1992) found that many dives were required to find appreciable densities of purple sea urchins. In areas where sea urchins were found sub-tidally, densities ranged from 3 to 130 /m^2.

S. purpuratus is able to tolerate a wide range of temperatures because it is adapted to live intertidally. A detailed study by Farmanfarmaian and Giese (1963) showed the species could survive temperatures ranging from 2° to 23° C if given time to acclimatize. The upper thermal limit was 25° C. Animals exposed to this temperature died within 24 hrs. At lower temperature extremes, urchins loose the ability to make coordinated movements. This is important for animals living intertidally because exposure to freezing temperatures or low sea surface temperatures could make them vulnerable to predators or physical damage from exposure to surf. The thermal limits on egg development are more restrictive. Eggs will develop normally at temperatures ranging from 13 - 20° C, they can, however, tolerate temporary cooling and continue to develop normally once re-warmed. *S. purpuratus* is however less tolerant of differences in salinity, (28 to 38.5 ppt) and low levels of dissolved oxygen.

Reproduction

S. purpuratus is a broadcast spawner with a swimming larval period of 2-3 months before settling to the benthic stage (Strathmann, 1978). Reproduction in purple sea urchins has been extensively studied (Bennet and Geise, 1955; Boolootian and Giese, 1959; Gonor, 1973a, b; Lasker and Giese, 1954; Lawrence et al. 1965). Spawning is annual with the gonads increasing in size in the fall (Oct.-Dec.), decreasing during winter (Jan.-Mar.) and smallest during summer (June-Aug.) (Boolootian, 1966, Gonor, 1972, 1973a, b). Gonor (1973a, b) studied the reproductive cycles of *S. purpuratus* at three sites along the central Oregon coast. He found the three sub-populations he examined were synchronous in their annual cycle of gonad growth, gametogenesis and spawning. This is contrary to the findings of Ebert (1968) who found significant differences in the gonadal production cycles of *S. purpuratus* over very small spatial scales. Campbell (1992) reported that the timing of gonad maturation in BC agreed with that reported for Oregon.

Gonad indices are a measure of the proportion of an urchin's body weight that is gonadal tissue. Common indices include:

- wet gonad weight / total weight X 100,
- wet gonad weight / drained wet weight X 100;
- dry gonad weight / total dry weight X 100;
- gonad weight / test diameter X 100.

Kramer and Nordin (1975) found that the mean gonad index (wet gonad wt/drained wet weight) was 20.5 % in October, 1974, with a maximum of 42.2 % for *S. purpuratus* collected off Albert Head, BC. A value of 15 to 20 % (Mottet, 1976) is more desirable for market indicating the samples collected by Kramer and Nordin (1975) had matured past market condition. Campbell (1992) found that *S. purpuratus* gonad indices peaked in November and December of 1991 in BC waters but displayed a high degree of variability in April and May of 1992.

In Oregon, intertidal *S. purpuratus* begin to produce mature gametes at 24 mm test diameter during the second year of life; by 40 mm TD all individuals have mature gametes (Gonor, 1972), however size at first maturity has been reported down to 16 mm (Kenner and Lares, 1991).

Gonad development

Gonadal development in urchins has been divided into 5 stages (Chatlynne 1972, reviewed in Gonnor (1972a); Miwa, 1966, reviewed in Mottet, 1976). In Stage I, the resting stage, the size of the gonads is at a minimum. Either spawning has recently occurred or the urchin is still immature. The gonads do not contain eggs or sperm, but the sex of the urchins can be determined microscopically. Near the gonad walls, spermatogonias will be present in males and oogonias will be present in females. The gonads of well fed urchins at this stage account for 5 – 10 % of the body weight.

During Stage II, the developing stage, the urchins eat actively and excess nutrients are stored in the gonads. Spermatocytes and oocytes are produced, but the male and female gonads are still indistinguishable except under a microscope. At this stage the gonads reach 15 to 20 % of the urchin's wet body weight and water content is at a minimum.

In Stage III, the pre-mature stage, the gonad weight approaches its maximum. Eggs and sperm are produced and, as the number of these sex products increases, the coloration of the gonads changes so the sexes can be distinguished visually, females being darker orange than males.

The weight of the gonad reaches a maximum during Stage IV, mature, and the gonads may weigh up to 25 to 40% of the total weight (Kramer and Nordin, 1975).

Stage V is the spawning stage and it corresponds with a rapid drop in the size of the gonad. As this decrease occurs, the fluids surrounding the gonads (the perivisceral fluids) increase in volume to make up the difference. Late in stage II and early in Stage III is when market quality is at its peak.

Gametes accumulate in the gonads until some stimulus, an increase in temperature or the presence of gametes in the water (Gonor, 1973), induces spawning. When stimulated, muscles contract and squeeze the gonads, forcing the eggs or sperm out pores (gonopores) in the genital plates into the sea. Other stimuli shown to induce spawning include a 10-volt current (Harvey, 1954) injecting the following into the peristomal membrane: air (Dixit, 1973), acetylcholine (Koshida, 1973) and potassium chloride (Fueseler, 1973).

A number of factors have been shown to influence the success of fertilization and development in echinoderms including population density, increases in spawning aggregation size, and decreases in flow velocity (Levitan, 1991; Levitan et al. 1992; Mead and Denny, 1995). The impact of dilution of gametes and hydrodynamic shear may be contributing factors affecting the periodicity of recruitment in *S. purpuratus*.

The importance of "Allee effects" to the management of red sea urchins was reviewed by Ebert et al. (1998). Allee effects are defined as any mechanisms that can lead to a positive relationship between an individual's fitness and either the numbers or densities of conspecifics (Stephens and Sutherland, 1999). Mechanisms include but are not limited to antipredator aggression, predator swamping, modification of the environment, and facilitation of reproduction. It was noted that positive density dependence could impact red sea urchins at two points in their life history: 1) density dependent fertilization rate and 2) survival of post-settlement juveniles due to protection from the spine canopy of adults. Allee effects for purple sea urchins are likely similar. Reduced sperm concentrations (spawner density) resulted in reduced fertilization rates in red, purple and green sea urchins (Levitan, 1991, 1992, 1998). Settlement of newly metamorphosed *S. purpuratus* larvae under the spine canopy of adult conspecifics has been documented (Eberts, 1968). The shorter spines and smaller adult size limit the ability of the adults to shelter juveniles, however, there may be interspecific Allee effects because purple sea urchins will settle under the spine canopy of large red sea urchins gaining some refuge from predators.

Larval development

Figure 4 from Mottet (1976) shows the development of an echinoderm larvae from egg to an echinoderm larva or echinoplutei. These larvae are bilateraly symmetric and bear no resemblance to the adult. They have four, and later eight, "arms" which are directed up-wards, and they have ciliated bands, which they use for locomotion and food collection (Strathman, 1971). Fertilised eggs will develop into larvae in 2 – 4 days.

Late in the development of the larvae, some of the juvenile organs begin to form. The habitat and food of larvae and juveniles are so different that few, if any, of the larval organs give rise to comparable organs in the adult (Hinegardner, 1969). As more of the juvenile organs develop and the oral half of the juvenile appears, it almost seems like a parasite absorbing nutrients from a host.

Settlement

Larval settlement has been well studied for *S. purpuratus* (Strathman, 1978; Cameron and Schroeter, 1980; Eberts et. al. 1994; Hinegardner, 1969). When sufficiently well developed, the larvae will begin to seek a suitable substrate to settle on. If a suitable surface is not available, the larval phase will continue, although the larva will grow little (Hinegardnre, 1969). Surfaces covered with sessile diatoms or bacteria will induce settlement in urchins. After settling, metamorphosis is rapid. Within an hour, the larval tissues are displaced and a tiny sea urchin with spines and tube feet emerges. During the next 4 or 5 days the nutrients from the rest of the larval tissues are absorbed while more of the internal organs of the sea urchin appear. Then the juveniles begin to feed much like the adult. The entire process from fertilization to settlement takes at least 63 to 86 days for *S. purpuratus*, 62 –131 days for *S. franciscanus*, and 51-152 days for *S. droebachiensis* (Strathmann, 1978). All studies of echinoderm larval periods have taken place in the laboratory, consequently little is known of the actual oceanic larval period. Field studies using settlement collectors suggest either extremely long larval periods (4 to 6 months) or periodic year round spawning events (Eberts et al. 1994).

Recruitment

Recruitment in *S. purpuratus* has been studied for over 30 years (Ebert, 1968; Strathmann, 1978; Cameron and Schroeter, 1980; Kenner 1992; Schroeter et al. 1996; Ebert et al. 1994). Echinoderm larvae spend weeks or months in the pelagic realm during which time they may travel hundreds of kilometers from their origin before they are competent to settle. They may be moved offshore, brought back onshore, or kept at or away from suitable sites by process acting at several scales (Ebert and Russell, 1988). Differences in settlement and recruitment at a specific site represent an integration of processes acting over large spatial scales (Parrish et al. 1981; Ebert 1983) as well as locally (Gaines and Roughgarden 1985; Connell 1985). Ebert (1983) studied *S. purpuratus* annually from 1964 to 1978 in tidal pools at Sunset Bay, Oregon. He noted substantial recruitment in 1963 then none between 1964 and 1978 at the same location and concluded that recruitment was highly sporadic. Tegner and Dayton (1981), however, reported recruitment of *S. purpuratus* as substantial and annual in the Point Loma kelp forest near San Diego California. Subsequently, growth and recruitment were proposed to have a latitudinal cline (Ebert, 1983). Russell (1987) studied recruitment at three sites: Pachena Point, BC; San Diego, California; and Punta Baja, Mexico, and found there was no correlation between latitude and recruitment, finding a higher degree of recruitment variability within sites than among sites. A detailed study undertaken by Ebert and Russell (1988) looked at size frequency data from central California to central Oregon, (36 ° N and 45 °N) and found that recruitment events inferred from size frequencies were correlated with major topographic features. Capes and headlands, predictable sites of upwelling and locations of cold water plumes had size frequencies indicative of low recruitment rates. Sites without predictable upwelling or regions that were between headlands had size frequencies that indicate substantial annual recruitment (Ebert and Russell, 1988).

The major currents that could impact larval dispersal on the BC coast are described by Thomson (1981; Thomson et al. 1989; Fig. 5 and 6). In winter, October through March, currents flow predominantly northward along the BC coast as part of a larger system known as the “Davidson current” which originates at about 40° N latitude. Surface transport is principally onshore during this period due to downwelling driven by the predominantly southeasterly winds. In April the spring transition takes place during which the northward flowing outer shelf current switches direction and flows south from May through August. This current is known as the shelf break current and displays weak upwelling, which results in predominantly offshelf transport. The fall transition is in September when the currents revert to their winter patterns. Along the west coast of Vancouver Island the “Coastal Current” persists throughout the year dominating near-shore processes with predominantly onshore transport. Other features of the local oceanography include gyres at the mouth of the Strait of Juan de Fuca, Cape Scott and Cape St. James. The net effect of these currents on *S. purpuratus* recruitment is unknown, however, one might speculate that recruitment along the west coast of Vancouver Island should be reasonably frequent with onshore transport and larval entrainment. Alternatively the myriad of small topographic features along the West

Coast of Vancouver might disrupt onshore transport sufficiently to limit recruitment, particularly at smaller spatial scales.

Campbell (1992) examined samples of *S. purpuratus* collected during an experimental permit fishery that ran between 1989 and 1992. He inferred recruitment from size frequencies and suggested the lack of smaller urchins indicated low recruitment of subtidal *S. purpuratus* on the southwest coast of Vancouver Island, between Tofino and Sombrio Pt.

Age, growth and mortality

A number of authors have studied growth rates and resource allocation in *S. purpuratus* (Ebert 1968; Russell, 1987; Swan, 1961; Lewis et al. 1990). Growth is not constant throughout the year. Highest growth occurs between July and December, lowest growth between January and March and intermediate growth from March to July (Ebert 1968). Growth in *S. purpuratus* can be variable from area to area, but is generally slow and dependent on habitat and environmental conditions (Edwards and Ebert 1991). Food availability impacts growth rates with growth being negative under highly crowded conditions (Levitan 1988) and/or low quantities of food (Ebert 1968; Bureau 1996; Ebert 1980). Under conditions of low algal abundance, urchins respond by allocating more resources to growth of the jaw and Aristotle's lantern (Ebert 1980; Bureau 1996; Lewis et al. 1990) to improve grazing efficiency. Exposure to wave action can reduce growth by causing spine loss and other physical damage which must be repaired (Ebert 1968); frequent spine damage results in overall increases in calcification. When spines are broken more frequently, as with the onset of winter storms, calcification of the test as well as the spines would clearly have survival value for urchins living inter-tidally on exposed rocky shores (Edwards and Ebert 1991)

In an early study Swan (1961) studied the growth of green sea urchins *Strongylocentrotus droebachiensis* on the coast of Maine and New Hampshire, as well as *S. franciscanus, S. droebachiensis* , and *S. purpuratus* at Friday Harbour, Washington State. Animals were fed an unrestricted quantity of *Laminaria digitata* in Maine and New Hampshire and Nereocystis at Friday harbour. He found that *S. franciscanus* had the highest growth rate, *S. droebachiens* showed intermediate growth. *S. purpuratus* displayed a relatively low growth rate but the large size attained by purple sea urchins indicated it must continue to grow, at a reduced rate, for a longer period. Ebert (1967) studied the growth of tagged *S. purpuratus* in the field estimating that 2 year olds would be 30.2 mm in diameter, 3 year olds 36.6 mm and 10 year olds 49.5 mm. Size frequency data collected from untagged individuals at the same site corroborated his findings with 1 year olds being 16.5 mm, 2 year olds 24.4 mm, and 3 year olds being 35.0 mm.

A number of skeletal structures have been examined to determine the feasibility of aging sea urchins including the spines, the jaw, interambulacral plates, and genital plates (Crapp and Willis 1975; Pearse and Pearse 1975; Gage 1991). Very few have met with any degree of success. Gage (1991) used coronal plates to age *Psammechinus miliaris* and found that it was difficult to reliably age urchins, especially older slow growing urchins, due to the presence of anomalous bands (additional annuli) and the presence of fine dark lines interrupting the growth zone. Ebert (1988) looked at the jaws of *Echinometra mathaei* and interambulacral plates in *S. purpuratus*. He found it possible to detect one natural line added per year in some fast growing individuals but others showed two or three lines (annuli) per year. For older slow growing or non-growing individuals it was not possible to resolve annuli and therefore age readings for larger individuals would be underestimates. Breen and Adkins (1976) attempted to age *S. franciscanus* from BC waters using interambulacral plates. Following the procedures of Ebert (1975) they found it was not possible to age *S. franciscanus* using this structure because observed rings were neither annual nor semi-annual and the number of rings present in similar sized individuals varied greatly. Negative growth and resorbtion of calcite from skeletal structures (Ebert, 1967) further complicate the aging of urchins. New methods are being developed using rotules (Fig. 3)(B. Campbell, pers. com; Robinson and MacIntyre, 1997) that show promise for future aging in urchins

Age validation studies have been undertaken (Ebert 1985, Gage 1992). The most significant finding of these studies was that tetracycline, an antibiotic used to mark age structures because it fluoresces under UV light, did not negatively impact the growth of *S. purpuratus* or *S. franciscanus* (Ebert, 1985; Bureau 1996).

Longevity of purple sea urchins can be up to or greater than 50 yr. (T. A. Ebert, pers. comm.). The estimate of 50+ years is based on estimated growth, derived from tagging studies, and observed size structure.

Russell (1987) determined growth parameters (Richards function) for *S. purpuratus* in tidal pools at Pachena Point, BC in 1981-82 by tagging the sea urchins with tetracycline and collecting them a year later. Generally, growth was slow and highly variable between individuals and between sites. Using the same data, Russell calculated instantaneous mortality rates (Z), annual mortality ($1-e^{-Z}$), and average lifespan following recruitment (1/Z). The mean instantaneous mortality rate was 0.119, the minimum 0.087 and the maximum was 0.159. The mean annual mortality, was 11 % with a minimum and maximum of 8.28 % and 14.7 %. Mean estimated life span was 8.8 yr., with a range of 6.27 to 11.56 yr. The applicability of these values to subtidal population of *S. purpuratus* is unknown given that the models used assumed constant recruitment and were fit to size frequency data from tide pools.

For comparison we can compute natural mortality using Hoenig's (1983) generalized equation to estimate mortality rates from longevity data:

$$\ln(Z) = a + b\ln(t_{\max})$$

Where the intercept, a = 1.44, and slope, b = -0.982, for all taxonomic groups were used. An estimated maximum age (t_{max}) of 50 yr. resulted in an estimated instantaneous mortality rate of 0.0906. The close correspondence between this value and Russell's (1987) values support a Z value between .09 and .11.

Food

One of the factors contributing to the success of sea urchins is their ability to feed on almost any type of food. *S. purpuratus* is a herbivore utilizing algae, primarily drift algae, as the chief food source. Animal matter, however, is scavenged when available and the purple sea urchin has been shown to absorb dissolved organics directly through the tube feet. Leighton (1966) studied the feeding habits of several kelp bed invertebrates by providing equal quantities of seven species of algae and recording what was eaten. Of the algae consumed by *S. purpuratus*; 28 % was *Macrocystis pyrifera*, 20 % was *Laminaria farlowii*, 16 % was *Gigartina armata*, 13 % was *Egregia laevigata*, 11 % was *Eisenia arborea*, 11 % was *Pterygophora californica* and 1 % was *Cystoseria osmundacea*. At 5° C the daily ration was 1.7 % of its body weight at 15° the ration increased to 6.4 %, at temperatures in excess of 17° C the daily ration decreased. Vadas (1977) studied the feeding habits of *S. franciscanus* and *S. drobachiensis* finding that both species preferred *Nereocystis luetkeana, Costaria costata, Laminari saccharina and L. groenlandica* noting that *S. purpuratus* displayed similar preferences.

Predators

Purple sea urchins are preyed upon by a number of animals including the spiny lobsters, *Panulirus interruptus* (Tegner and Dayton, 1981), several sea stars, including: *Pycnopodia helianthoides, Astrometis sertulifera, Dermasterias imbricata, Pateria miniata* and *Pisaster ochraceus* (Tegner and Dayton, 1981; Dayton 1975; Ricketts and Calvin, 1939), the California sheephead fish, *Semicossyphus pulcher* (Tegner and Dayton, 1981) and sea otters, *Enhydra lutris* (Breen et al. 1982; Dayton, 1975; Estes et al. 1978). *Astrometis sertulifera*, *Panulirus interruptus* and *Semicossyphus pulcher* are not found in BC waters, leaving *Pisaster ochraceus*, *Pycnopodia helianthoides* and, *Enhydra lutris* as the major natural predators on *S. purpuratus* in BC waters.

Next to humans sea otters are the most important predator on sea urchins in British Columbia (Breen, 1980). After the re-introduction of sea otters on the northwest coast of Vancouver Island urchin abundance decreased and algal biomass increased (Breen at al. 1982; Watson, 1993). Where sea otter foraging was intense previously urchin dominated communities became algal dominated (Watson, 1993).

Sea otters have been identified as a keystone species for Pacific Northwest nearshore communities (Estes et al. 1978). By reducing sea urchin abundance sea otters promote the growth of kelp beds and this in turn may affect populations of other invertebrates and fish (Breen at al. 1982).

Diseases and Parasites

Diseases have caused moralities in many natural and captive populations of echinoderms. Mass moralities attributed to disease have been reported globally: *S. franciscanus* in California, USA, *S. droebachiensis* in Nova Scotia and Norway, *Diadema antillarium* in the Caribbean, *Paracentrotus lividus* in the Mediterranian, Brittany and France (Scheibling and Hennigar 1997; Gilles and Pearse 1986; Jangoux 1987). Mass mortalities of *S. droebachiensis* in Nova Scotia have been attributed to the marine amoeba, *Paramoeba invadens*, (Jones and Scheibling 1985). In Japan the cultured sea urchin *S. intermedius* suffered large-scale moralities after sorting and grading, prior to shipment to market. External signs of the disease were blackish purple lesions on the surface with progressive loss of spines, a short rod psychrophilic bacterium, belonging to the genus *Vibrio* was isolated as the causative agent (Tajima et al. 1998).

Echinoids dying in mass mortalities often possess characteristic lesions on their tests. These lesions involve a central necrotic region of disorganized skeletal tissue surrounded by a ring of swollen tissue. The lesions can grow until they perforate the test and the animal dies presumably from internal infection. In some cases however the disease is checked, the animal recovers and test heals (Gilles and Pearse 1986). Diverse microorganisms have been observed in the necrotic area of the lesion including masses of bacteria, algae, ciliates, nematodes and microarthropods (Johnson, 1971; Maes et al. 1985)

Gilles and Pearse (1986) collected naturally occurring diseased purple sea urchins from the Monterey Bay area to study the basic characteristics of diseases in sea urchins. Diseased urchins were identified by the presence of lesions on the test and occurred at an incidence of 1 in 1000. Bacteriological sampling of lesion material revealed the presence of 14 bacterial strains including *Virio*, *Aeromonas*, *Flavobacterium*, and *Pseudomonas*. When isolated in the lab and tested for pathogenic potential only two of the isolates, *Vibrio anguillarum* and *Aeromonas salmonicida*, were able to initiate lesions. Experimental infectivity tests determined that a stress such as injury was necessary for the formation of lesions. Tajima et al. (1998) also noted the requirement for a stress (injury) before infection could be induced in *S. intermedius*.

The internal parasites of *S. purpuratus* include ciliated protozoans and the flatworm *Syndisyrinx fransiscanus* . External commensals include the purple polychaete, *Flabelligera commensalis* and the isopod *Colidotea rostrata* living among the spines (Morris et al, 1980)

Echinoderms and Kelp Forest Ecology

Most sea urchins are primarily herbivorous (Johnson and Mann, 1982) often regulating the abundance of marine plants in shallow water marine environments (Lawrence, 1975). Echinoids have been held accountable for the deforestation of vast areas of kelp-forest habitats in many different parts of the world (Harold and Pears, 1987). Density of echinoids is an important factor in determining grazing intensity. Under extreme grazing pressure urchin barrens are formed as almost all algae is consumed except the hardy species such as corallines and some opportunistic algae (Lawrence and Sammarco, 1982). Harold and Pearse (1987) reviewed the interactions between urchins and kelp beds and suggested that the ecological role of echinoids seems to be all or none. Urchins will generally stay in cryptic habitats and feed on drift algae, having little or no impact on the attached plants. When conditions change and some threshold is reached urchins move out of their cryptic habitats and start feeding on attached algae. The lower depth limit of kelp forests commonly coincides with high densities of urchins (Harold and Pearse, 1987).

Where there are dense urchin populations, urchin grazing largely accounts for the limited distribution of macroalgae in shallow waters (Himmelman et al. 1983). Removal of *S. droebachiensis* in shallow subtidal rocky habitats on the east coast of Canada, caused a large increase in algal species diversity and algal abundance increased about 125 fold after two years (Himmelman et al. 1983). Small urchins which had not been removed showed a high growth rate indicating strong intraspecific competition for food.

Paine and Vadas (1969a) observed increased algal abundance and species diversity after removing *S. purpuratus* from tide pools and *S. franciscanus* from subtidal areas in Washington. Levitan (1988) showed algal biomass increased 30 fold after a mass mortality event killed 99 % of the urchin *Diadema antillarum* in the US Virgin Islands. Subsequent increased growth, as a result of the increased food supply, resulted in a 42 fold increase in the biomass of urchins which in turn lead to an 84 % decrease in algal biomass. Scheibling (1984) reported similar findings following a mass mortality of *S. droebachiensis* in Nova Scotia. Duggins (1980) removed red, green and purple sea urchins in Torch Bay Alaska resulting in a dramatic increase in algal biomass and diversity.

Stock unit

The term Meta-population (Levin, 1969) describes a population of populations. With the wide geographic range of *S. purpuratus,* covering aproximately 30◇ of latitude, and the potential for a high degree of larval dispersal or exchange due to the protracted larval stage, it could be well described as a meta-population. Consequently the entire west coast of North America may constitute a single stock. Differences in size composition, size at first maturity and recruitment have been noted between northern (Oregon) populations and southern (California Bight) populations indicating some degree of stock differentiation. Point Conception in California marks the range limits for numerous species where the cold southward flowing California Current moves offshore allowing warmer water to accumulate in the California bight. Recent work with allozymes and mitochondrial DNA in *S. purpuratus* at sites along the west coast of North America revealed a genetic mosaic where differences over short distances could exceed differences over much larger distances (Edmands et al. 1996). A mild break in haplotype was observed about 300 km south of Point Conception. This lends some support to the hypothesis that purple sea urchins can be divided in to northern and southern stock components in the area of Point Conception.

Lore

Several people have offered their personal observations of *S. purpuratus* in BC waters (MavKinson and Nottestad, 1998). When and *S. franciscanus* and *S. purpuratus* co-occur in BC waters, *S. purpuratus* is distributed from the feed line, the upper depth limit at which *S. franciscanus* feeds, towards shore (Dominique Bureau, PUHA (Pacific Underwater Harvester Association), pers. comm.) Commercial fishers have reported *S. purpuratus* moving into habitats formerly occupied by *S. franciscanus* following harvest (Rick Strong, Brad Carey, commercial urchin fishers, pers. comm.) An interesting behavioral note was reported by Rick Strong, he noted that *S. purpuratus* seem sensitive to low pressure systems because they appear to move into crevices before storms arrived. Purple sea urchins form very dense aggregations when under foraging pressure form *Pycnopodia helianthoides* (John Schaefer, pers. comm. ODFW). Sunflower stars avoid these dense patches to avoid being stung by the pedicellaria of numerous urchins. Pycnopodia preferentially prey on *S. purpuratus* over *S. franciscanus*, the longer spines of the later affording it more protection. When *S. purpuratus* and *S. franciscanus* are placed singly in the path of a foraging Pycnopodia, the purple sea urchin will be eaten (John Schaefer pers. comm. ODFW).

Review of Sea Urchin Fisheries

Alaska

The green sea urchin *Strongylocentrotus droebachiensis* is harvested commercially in the Central and Westward Regions of Alaska. The fishery began in 1985 and all the catch is taken in the Kodiak area. In the Southeast Region, the harvest is restricted to the red sea urchin *Strongylocentrotus franciscanus*. The fishery began in 1981 occurring mostly in the Ketchikan area (Woodby, 1992). The fishery is managed on a conservative surplus production model that allows an approximate 3 % rate of harvest on an annual basis. Biomass is estimated from joint industry and Department of Fish and Wildlife surveys. Portions of southeastern Alaska were closed from 1989 to 1996 due to concerns over sea otter predation. No fishery exists for purple sea urchins in Alaska. Landings for all urchin fisheries, species combined, by state or province are presented in Table 1. Urchin landings in Alaska peaked in 1997 and may continue to increase given that quota allocations were not achieved in 1997. The overall decline in world prices for urchin roe and problems with quality, will probably regulate the expansion of the fishery.

Washington

The sea urchin fishery began in Washington State in 1971. Landings peaked in 1988 at 3600 t but have returned to historic levels (about 500 t) and remain stable. Green and red urchins are harvested under the same license with fishers harvesting species quotas by district. The quotas have been derived differently for each species. Between 1987 and 1996 the fishery was managed on the basis of a 3 year rotation. Biomass was estimated from surveys conducted between 1977 and 1995 using pre and post-harvest density estimates and change-in-ratio methods to derive estimates of pre-harvest biomass (A. Bradbury, pers. comm. Lai and Bradbury, 1998). The exploitation rate was set at 10 % for each area, this allowed for two years of undisturbed growth in each area before re-harvest. The rotational closure had to be abandoned following a court decision allocating 50 % of the urchin harvest to local native bands. Currently, red urchins are harvested at a fixed annual exploitation rate of 3 – 5 %, quotas are set by district. For green urchins, arbitrary quotas (408 t) were set at the inception of the fishery and CPUE (Catch Per Unit Effort: usually the catch weight divided by the time fished typically kilograms per minute in urchin fisheries) monitored; a decline in CPUE would result in a reduction in quota. The quota was reduced to 272 t in 1992. The most western fishing district was closed in 1995 due to sea otter re-colonization and consequently reduced urchin biomass.

Oregon

The development of the urchin fishery in Oregon began in 1986. The fishery expanded rapidly between 1989 and 1991 but subsequently stabilized. Only red and purple urchins are harvested in Oregon. Landings of red urchins peaked in 1991 at 4220 t, and have declined since to the current level of 150 t. Fishers cite ongoing quality problems as the result of low algal food abundance and poor export market conditions as reason for the reduced landings. Red urchins are managed on the basis of limited entry license (which is forfeit to the state if 5000 pounds of urchins are not landed on the permit), and a minimum legal size limit of 89 mm (3.0 in.)(Richmond et al. In press)

The purple sea urchin fishery in Oregon began in 1991. Urchin harvest regulations were modified so existing permit holders could harvest purple sea urchins. As a condition of the permit, pre-harvest surveys were required, with divers providing density and random size frequency data as well as detailed survey maps. From the survey data, the average density of legal-size urchins was calculated and multiplied by the survey area. Density is converted to weight and a policy of fishing mortality (F) equals natural mortality (M) is applied. The average fishing mortality used is 0.125 but is scaled down to 0.1 if the proportion of sub-legals in the population is low. The coast wide quota for *S. purpuratus* in Oregon is 274 t (605,000 lbs, Table 2). Landings (Table 3) rose to 89 t in 1994 but has subsequently dropped. Most of the 1994 harvest came from Simpson Reef off Cape Arago. Post harvest surveys indicated that almost all *S. purpuratus* had been removed from the area (N. Richmond, pers. comm. ODFW). Harvests from other areas have been limited. Current abundance is very high but gonad quality is very poor due to low algal abundance and high intra-specific competition for food (J. Schaefer pers. comm.; Richmond et al. In press)

California

As in Oregon, both purple and red sea urchins are harvested in California (Kalvass and Hendrix, 1997). The fishery for *S. franciscanus* began in the southern region of the state around 1970 and was confined to that area until about 1985 when fishers began to harvest virgin stocks on the states Northern Coast (Kato and Schroeter, 1985). The fishery leap-frogged central California due to a paucity of marketable sea urchins largely attributed to the presence of the sea otter, *Enhydra lutris*. Landings for southern California peaked in 1981 at over 10,000 t and have remained stable at an average 9762 tons per year. Landings from northern California peaked at 13,605 t in 1988 and subsequently declined to 2,148 t by 1995. Prior to 1985 fishers required only a commercial fishing license to harvest urchins. In 1985 permits were required to harvest sea urchins and 2 years later a moratorium was placed on the issuance of new permits. Size limits were introduced in 1989. Effort controls, in the form of limiting the number of days fished per week, were introduced in 1990. In 1994, virgin biomass was estimated for northern California (Kalvas and Hendrix, 1997) with a depletion estimator driven by CPUE and cumulative catch. The model predicted a pre-fishery biomass of 76,290 t for northern California with a cumulative catch of 50,800 t and a sustainable harvest of 6103 t. This could have been achieved by applying a conservative 8 % harvest rate to the stock estimate to avoid the boom and bust cycle which resulted in a harvest of 1534 t in 1998

(Peter Kalvass, pers. comm.). Declining catches have been blamed on weak markets and El Niño which caused a reduction in kelp biomass and sea urchin gonad quality.

Interest was first expressed in developing a purple urchin fishery in California in 1989 (Pleschner, 1992). An experimental fishery took place in 1990 with a grant from the Local Marine Fisheries Impact Program. Approximately 22,500 kg was landed and shipped to Japan live (Steele and Pleschner, 1991). Landings have varied since never amounting to more than about 1 % of the harvest of red sea urchins (Table 3) (Kalvas and Hendrix, 1997). The urchins were harvested in August-September, when gonad quality was at a peak, suggesting a maturation schedule different from that in Oregon and BC. Participation in the fishery has been very limited with the majority of landings coming from a few fishers.

John Duffy with the California Department of Fish and Game, provided the following synopsis of the California purple sea urchin fishery:

> “ I would class our purple sea urchin fishery as a "low level" on-going fishery, small in comparison to our red sea urchin fishery with an annual high of something like 300,000 pounds and more typically under 100,000 pounds. The product has been a good one, but there have been problems with actually developing it as a stable fishery: 1) the roe quality is much more seasonal than that of the red sea urchin - I think it was a question of being really marketable for only a couple of months a year, compared to almost year - round high quality red sea urchin roe; 2) higher processing costs - in Calif., the labor costs of processing the product are a key element in success for the processors and because of the small size and (relative to red sea urchins) low yield it wasn't a favored way to go; 3) fisherman incentives: with red sea urchins so abundantly available (20 to 50 million pounds per year in the 1980s through about 1996) no one wanted to spend the time to harvest the smaller purple sea urchins. There was some work done on how to pick, pack and ship live purple sea urchins for the export market; and a couple of divers tried it out but no one seemed to stay with it, probably because of the first reason above. “

Mexico

A commercial fishery for *S. purpuratus* has recently begun in Baja California, Mexico. There are currently no resource management regulations governing this species and no assessment of the resource (Vélez-Andrade and Sosa-Nishizaki, 1998).

Urchin Fisheries in British Columbia

Red Urchin (*Strongylocentrotus franciscanus*) fishery

The Red Urchin (*Strongylocentrotus franciscanus*) has been fished commercially in British Columbia since the early 1970s (Bernard, 1977). Landings started to increase rapidly in the early 1980s for the south coast of BC and the late 1980s for the North coast. The fishery peaked in 1992 with over 12,000 tons landed, but subsequently landings were reduced and stabilized by arbitrary quotas at approximately 6000-7000 tons per year coastwide (Campbell and Harbo, 1991; Campbell, 1995). Regulation of the fishery has included minimum and maximum size limits, area rotation closures, effort controls (4 day workweek) and license limitations (Campbell and Harbo, 1991; Heizer et al. 1997). Early surveys were conducted to determine size composition and abundance of red sea urchins (Bernard and Miller, 1973; Breen et al. 1976, 1978; Adkins et al. 1981; Sloan et al. 1987). A quota for the south coast was established in 1985 based on a 5 % exploitation rate. Subsequently, as the fishery expanded estimates of standing stock, and consequently, quotas, were based on consultation with fishers. Management of the North coast fishery progressed from an unregulated, open fishery prior to 1989 to regulation by size limits between 1989 and 1992 and regulation by quota from 1993 onward. The north coast quota was arbitrary and based on historical landings but deemed necessary due to exponential increases in annual catch. License limitation was introduced in 1991 reducing the number of licenses to 102; this has subsequently grown to 110 by 1994. In 1994 the Pacific Underwater Harvesters Association (PUHA) requested an Individual Vessel Quota (IVQ). The implementation of IVQ required quota estimates. Campbell (1998) estimated quota for north and south coasts using a combination of logbook and survey data, and published mortality rates for *S. franciscanus* from Alaska, BC and California by applying conservative scaling factors to natural mortality rates in Gulland's (1974) calculation of Maximum sustainable yield (MSY).

Green Sea Urchin (*Strongylocentrotus droebachiensis*) fishery

The fishery for green sea urchins on the BC coast developed rapidly from 1987 to 1991, and peaked in 1992 with landings of 1042 t. Declining landings and catch per unit of effort followed and management restrictions were implemented in 1992 followed by quota limitation in 1994 and an IVQ system in 1995. A size limit of 40 mm was put in place at the inception of the commercial fishery in 1987 the size limit was raised to 55 mm in 1988 and has been maintained. Quota limitations for the south coast, imposed in 1994, were arbitrary and based on the five-year average landing for the fishery from 1987 to 1991. In 1995, a review was conducted (Perry et al. 1998) and quotas calculated. As is the case with red urchins the management of the fishery was divided into north and south components, the south coast was further divided into Strait of Georgia, north (Pacific Management Statistical Areas (PFMA) 11-13) and south (PFMA 17-20, 28). A biomass dynamic model driven by logbook CPUE was used to compute Maximum Sustainable Yields (MSY) for the three areas, although it was recognized that MSY for the north coast was preliminary given the paucity of data catch data. Perry and Waddell (in press) review the green urchin fishery and update the Biomass dynamic model.

Purple Sea Urchin (*Strongylocentrotus purpuratus*) Permit Fishery

An experimental permit fishery for purple sea urchins took place on the BC coast between 1989 and 1992. The first permits were issued in the fall of 1989, for the September 1989 to May 1990 fishing season. A total of 23 permits were issued to 13 vessels. Permits were valid for 1 to 3 months from the date of issue. Permits were issued for the following Management Statistical Areas (MSAs): 11, 12, 20, 21, 23 – 25 and 27. Despite a high initial interest, there was only one commercial landing late in the season from MSA 24. The urchins from this landing were shipped to Japan but the roe was too ripe and the processor asked that no more be shipped that season. Season was defined as running from September of one year to May of the next. During the 1990/91 season there were only 4 permits issued to three vessels, 3 in area 20 and 1 in area 24. Several small landings totaling approximately 400 kg from MSA 19 (probably MSA 20, there is a discrepancy between fisher logs – MSA 20, and sales slips – MSA 19. The fishing area is on the border between the two MSA) were recorded that season. There was renewed interest for the 1991/1992 fishing season. The renewed interest was due largely to license speculation. With limited entry in place and IVQs looming on the horizon for red and green sea urchins many fishers wanted to ensure their participation in any new urchin fishery. License speculation is driven by the increase in the value of licenses and quota allocations that result from the above noted management measures. A total of 16 permits were issued to eight vessels in areas 20 and 24. Although there were many interested fishers only 5 vessels (all belonging to one individual), landed purple sea urchins that season. A total of 55,463 kg were landed in 1991/92 all except 1470 kg came from a single site in MSA 20. Table 4 summarizes the landings from fish slips and Table 5 summarizes landings from the logbooks. Daily catch per unit of effort (CPUE) was calculated across divers from logbook data by dividing the daily catch in kg by the total dive minutes. The average CPUE was 3.4 kg/min, the range was 0.4 kg/min to 11.0 kg/min, which is comparable to CPUEs for the red urchin fishery. The reasons given for the lack of interest in fishing purple urchins is that it was difficult work in harsh conditions and was hard on both divers and equipment (Rick Strong, summary report on the commercial harvest of Purple sea urchins, unpubl.). Prosecution of this fishery would require fishers to work in the most exposed areas of the west coast of Vancouver Island during periods of the worst weather, the potential for fishers to be severely injured or killed is significant.

The initial design of the fishery allowed for up to four permits per statistical area on the West Coast of Vancouver Island, MSAs 20, 23, 24,25 26, and 27. Permits would also be considered for MSA areas 11 and 12. Permits were valid for 3 months after being issued. If not used within three weeks of issuance the permits were to be cancelled and reissued to other interested fishers. A number of conditions were imposed on the permit holders; they were to provide detailed harvest logs, chart locations and site descriptions for all days spent fishing purple sea urchins. Harvesters were to provide biological and abundance data, at their own expense, to the Department of Fisheries and Oceans (DFO). A biological consultant approved by DFO was required to oversee or conduct the data collection. As initially conceived, the biological sampling program was to require a pre-harvest survey of the density of purple sea urchins in an area of commercial density.

Density and biological characteristics were to be determined as follows:

1) Starting at the shallow end of the urchin distribution, purple sea urchins, inclusive of undersize, within a 1x1 m square quadrat, were measured to the nearest millimeter. All animals were removed as sampling proceeded. The quadrat was

flipped down slope and the measurements repeated, until 10 quadrats (the number of quadrats was reduced to 5 in September, 1990) were completed. Urchins from each quadrat were to be kept in separate bags for later counts / measurements.

2) If the urchin zone ended before 10 (5) quadrats were completed, a new transect was adjacent to the first but separated by 5m.
3) For each quadrat the following was recorded
   i) Total weight of purple urchins.
   ii) Individual sizes to the nearest millimeter.
   iii) Count number/sample.
4) All urchins from each quadrat were saved in separate lots and delivered fresh to the Pacific Biological Station in Nanaimo for measuring.

Ongoing sampling requirements included measuring 200 commercially harvested purple sea urchins from several cages following the first week of harvest. Measurements were to the nearest mm and a total weight for the sample, to nearest gram, was recorded. Once each month during the fishery, the harvester was required to measure a random sample of 200 commercially harvested urchins and deliver them fresh (within 24 hrs.) to the Pacific Biological Station.

Approximately 21 biological samples were collected and examined during the course of the fishery (Tables 6 and 7). Gonad quality was recorded and a gonad index was developed for 6 of these (Campbell, 1992). Survey densities of subtidal *S. purpuratus* ranged from 3 – 130 per m^2. Mean size ranged from 52 – 70 mm, the proportion of sub-legals in the population ranged from 2 to 62 %. Size composition data from port samples showed mean sizes of 61.1 – 68.1 mm and proportion of sub-legals ranging from 0.5 – 13.9 %. There was no discernable trend in size of the port samples during the fishery. Size composition data tends to be skewed towards larger individuals because the larger size classes represent an accumulation of multiple older age classes. Given the size composition of *S. purpuratus* harvested in Sombrio in 1992 it is likely that the harvest was composed primarily of older urchins.

Campbell (1992) reviewed the permit fishery and concluded that fishers complied with the requirements of their experimental permit during the 1991-1992 season better than the 1990-1991 season. Almost all of the data provided by fishers came from MSA 20. The quality of the size composition data was good for the port samples but of unknown quality from density surveys. He found the density data to be of poor quality and sample sizes too small. He concluded that having fishers provide data through consultants to be a nebulous method of monitoring the *S. purpuratus* experimental fishery. His recommendations included gathering more information on the recruitment growth, seasonal gonadal development, spatial distribution and size at maturity for sub-tidal purple sea urchins in BC waters, increasing the minimum legal size and having DFO or trained consultants conduct the pre and post-harvest density surveys.

The fishery was stopped after the 1992 fishing season for a number of reasons: There were concerns about the time and resources required to assess and manage the fishery at a time when successful fisheries for red and green sea urchin fisheries needed attention. There were also enforcement concerns with reported poaching of abalone and green sea urchins by those involved in the fishery (Rick Harbo, pers. comm.). Given the limited resources available at the time it was felt the fishery should be discontinued pending a review.

An industry survey sponsored by the BC Purple Urchin Association (BCPUA) was conducted between September 17 and 19, 1996 (Krause, 1996). The survey covered the area from Carmannah Point to Port San Juan on the west coast of Vancouver Island. The survey essentially prospected for purple sea urchins. The quantitative findings of the survey with respect to harvestable quota are based on unsubstantiated assumptions, and an unrealistically high exploitation rate, and are consequently of no use. However, notes on distribution and density are worth mentioning. Density data were obtained by placing a 0.25 m^2 quadrat in the middle of a cluster or patch of sea urchins and counting the animals, density estimates range from 0 to 340 per square meter. No data on patch size was collected and patch frequency was only mentioned at one site. The reported distributions where: 1) patchy from Carmannah Point to Walbran Creek 2) uniform but low density at Walbran Creek, 3) a very high density, 3-4 animals deep, large patch at Logan Creek and 4) a more or less continuous medium intensity band 2-3 meters wide parallel to the shore starting at 2 m depth from Cullite Creek to Port San Juan. While the data are interesting, a more comprehensive survey design would be required to estimate population abundance.

Small quantities of *S. purpuratus* are harvested each year in BC by scientific supply houses (Table 8), these quantities are not large ranging from 300 to 1743 animal per year for the last 4 years.

Discussion

Management and Research Considerations

Analytical approaches to urchin assessment and management have improved over the last decade to include a suite of useful methodologies including yield per recruit analysis, stock reconstruction, and quantitative biomass estimation. The management of urchin fisheries has likewise changed, evolving from unregulated and unmanaged to fisheries regulated by limited entry, quotas, time and area closures and size limits. The potential management measures, which could be applied to the development of a fishery for purple sea urchins, will be discussed. The data requirements for each will be considered:

Quotas: Before quotas can be assigned, some estimate of pre-harvest biomass, an understanding of the target species spatial distribution, and an estimate of natural mortality is required. The conventional techniques used to estimate the population abundance of red and green sea urchins involve estimating density from surveys, and measuring habitat or bed area from charts provided by the fishers. Density estimation methodology would need to be altered to accommodate the highly aggregated nature of purple sea urchins. The conventional broad brush survey practice of flipping a quadrat along a transect and counting and measuring the urchins in each m^2 quadrat is unlikely to cover enough patches of purple sea urchins to generate a meaningful density estimate. Counts by quadrat are useful for estimating abundance of species which are reasonably uniform or disaggregated over larger areas because the variance in counts between quadrants is relatively low. The results one could anticipate for purple sea urchins would include many 0s and a few very large values (Neil Richmond, ODFW, pers. comm). An alternative survey methodology needs to be developed. One possibility would be a two stage approach where the diver swims a long transects with a measuring tape and records the linear distance along the transect occupied by purple sea urchins. This would provide an estimate of the proportion of an area (proposed urchin bed) covered by purple sea urchins. The length of each patch would need to be recorded to estimate variance in patch size. Transect orientation would need to be determined prior to entering the water either by compass heading or by deploying a lead line from the surface. Transect orientation parallel to an iso-bath would be one approach given the limited depth distribution of *S. purpuratus*. Second stage sampling would involve randomly selecting patches along the transect and using a quadrat, flipped along a randomly selected axis of the bed, to obtain density counts and size composition data. By having a random sub-sample of bed size and density and size composition it would be possible to estimate total abundance for a given bed. Means computed from highly skewed distributions typically result in very large confidence intervals; stratifying and randomizing at several levels would reduce the confidence interval around the estimated abundance. The second piece of information required to set quotas is an estimate of natural mortality. Published values and a value computed in the section on age, growth and mortality suggest a range of 0.09 – 0.11 which agrees with values being used in other urchin fisheries. A detailed program of biological sampling from a variety of sites to collect size and age frequency data would further refine this estimate. Once a mortality rate has been computed an exploitation rate has to be selected, current precautionary exploitation rates for urchins are in the range of 0.25 – 0.50 (Z) which results in an overall exploitation rate of 2.3 to 5 % of the computed standing stock.

Size limits: The 55 mm test diameter size limits imposed during the permit fishery (1989-92) would seem effective at ensuring at least one and probably several spawnings prior to harvest. *S. purpuratus* are fully recruited to the spawning biomass at 40 mm test diameter in Oregon but it is not known if this is true in BC waters. As part of the biological sampling program detailed above maturity stage and gonad index could be monitored to ensure that the size limit provides an adequate spawning refuge for local stocks.

Area closures: Area based management is one of the tools available to fisheries managers but must be implemented at an appropriate spatial scale. By limiting the area available to fishers it may be possible to monitor fishery impacts directly. When large areas are open to exploitation, declines in catch rate, mean size or mean age may well take decades to be detected as stocks are serially depleted (Haaker et al. 1996). In addition by reserving large areas as unfished the fishery manager is provided with a buffer ensuring a significant proportion of the spawning population is protected. Given the patchy distribution, sporadic recruitment and longevity of purple sea urchins the most appropriate scale, at least initially, would be that of individual urchin beds (“Bed by Bed” management). By monitoring and validating catch statistics and undertaking a biosampling program it would be possible to determine the appropriate scale for area based management.

Seasonal closures: One of the reasons for seasonal closures in urchin fisheries is to reduce waste by limiting effort when there is little likely-hood of finding urchins with marketable row. Urchin fishers must break open or sample some urchins to determine whether or not the population in an area is in harvestable condition. Given the variability in maturation schedule shown by this species the potential for waste is great, although results from the 1991/92 fishery indicate good quality roe from November through January. Spatial and temporal variability in gonad index could be monitored through the bio-sampling program described above and if patterns become apparent measures can be taken.

Rotational fisheries: Rotational fisheries are a different form of time and area closure wherein an area is harvest at a higher exploitation rate for one season and left for a few seasons to recover. To determine the utility of this management action we need to know how the population responds to harvest. To address this would require establishing a series of study sites and applying different harvest strategies. The potential benefits with this management approach are improved yields in the longer term; with reduced handling damage from harvesters urchins can allocate resources to somatic growth and gonad production instead of repair.

Limited entry: Established at the outset of a new fishery can effectively control effort and reduce the possibility a “gold rush” fishery evolving. The establishment of quotas as described above would be essential to mangers in determining a reasonable level of participation (How many permits to issue).

All of the above management measures should be imposed concurrently on any fishery for purple sea urchins at the outset. As part of the above there must be a requirement for detailed logbooks, dockside validation, partial observer coverage and industry sponsored survey programs. By imposing stringent management measures from the beginning it may be possible to avoid the rapid expansion and resource depletion that has characterized many other fisheries.

The current status of our biological knowledge of *S. purpuratus* is summarized in Table 9. This table serves as useful reference when assessing research and management priorities.

Research Program

The following studies need to be undertaken, as part of the Phase 1 assessment should the Pacific Scientific Advice Review Committee (PSARC) feel the proposed fishery warrants further consideration.

- A series of joint industry/DFO surveys to ascertain the abundance and distribution of subtidal *S. purpurastus* in BC waters. Initially, the west coast of Vancouver Island, Sombrio, Barkley Sound, Tofino and Quatsino. Industry participation will require the formation of a harvesters association or the inclusion of an existing association.
- Establishment of a series of study areas to monitor life history parameters such as settlement, growth, recruitment and age.
- An intensive biological sampling program to be run in conjunction with the surveys. This will allow analysis of growth, recruitment, size at maturity, and provide insights into the appropriate spatial scale for management.
- Aging of samples collected during the biosampling program. This gives us a tool to estimate natural mortality (with a few years data), determine size at age and age at maturity.

Other research priorities/projects applicable to purple sea urchins:

- Developing a model (GIS) based approach to estimating abundance. A model could be built of the hypothetical distribution of *S. purpuratus* in a given area, that distribution tested and used to as a more cost effective means of biomass estimation.
- Evaluate the following as cost effective means of estimating habitat for subsequent use in estimating biomass. Arial photogrammetric surveys, which have been used to map 7 kelp beds in California, with the data used to estimate red urchin habitat area.
- Questar Tangent seabed classification tools.
- Drop camera data has been used to estimate the abundance of rockfish, sea cucumber and red sea urchins. Given that more camera drops can be made in a day than dives this approach might allow large area to be assessed cost effectively.
- Fishery impacts and potential Allee effects need to be determined.
- Intra-specific competition between red and purple sea urchins needs to be evaluated for potential fishery impacts.
- Study sites need to be established to monitor recruitment.
- Sampling for stock unit determination using DNA electrophoresis needs to be pursued to determine the appropriate spatial scales for management actions.

Summary

In the author's opinion there may be sufficient resource present in BC waters to support a small seasonal fishery. Significant effort will be required to assess the resource prior to the inception of a commercial fishery and to manage any fishery for purple urchins on an ongoing basis. While much is known of the biology, ecology, population dynamics and trophic interactions of *S. purpuratus,* very little of this information comes from BC. The key features of this animal's life history are longevity, slow and variable growth, variable recruitment, density dependant fertilization, and large stock unit size. Any fishery development for this species in BC would need to be cautious given the uncertainty regarding the abundance, recruitment and growth of this animal in BC waters.

Acknowledgements

I would like to thank the following people for providing me with data, references, and advice; Dr Tom Ebert, San Diego State University; John Duffy and Peter Kalvaas, California Department of Fish and Wildlife; Neil Richmond and John Schaefer, Oregon Department of Fish and Wildlife; Alex Bradbury, Washington Department of Fish and Wildlife; Dr Alan Campbell, Rick Harbo, Jim Morrison, and Dr. Dan Ware, Fisheries and Oceans Canada; Rick Strong and Brad Carie, commercial urchin fishermen. Gordon Miller and Annie Smith helped gather the literature.

References

Adkins, B. E., R. M. Harbo, and P.A. Breen. 1981. A Survey of the commercial sea urchin (*Strongylocentrotus franciscanus*) populations in the Gulf Islands, November 1980. Can. MS Rep. Fish Aquat Sci. 1618: 41 p.

Anon. 1998. Policy and guidelines for the development of new fisheries in Brithish Columbia. Draft document. Fisheries and Oceans Canada – Pacific Region, Government of Canada, Minisrty of Fisheries, Province of British Columbia. 6p + 1.

Austin, W. C. 1985. An annotated Checklist of marine invertebrates in the cold temperate Northeast Pacific. Khoyatan Marine Laboratory, Cowichan Bay, British Columbia.

Baldwin J. D., M. C. Pillai and G. N. Cherr. 1992. Response of embryos of the uerchin Strongylocentrotus purpuratus to aquueous petroleum waste includes the expression of a high molecular weight glycoprotien. Mar. Biol. 114, 12-30.

Bennet, J. and A. C. Giese. 1955. The annual reproduction and nutritional cycles in two western sea urchins. Biol. Bull. (Woods Hole) 109(2): 226 – 237.

Bernard, F. R. 1977. Fishery and reproductive cycle of the red sea urchin, *Strongylocentrotus franciscanus,* in British Columbia. J. Fish. Res. Board Can. 34:604-610.

Bernard, F. R. and D. C. Miller. 1973. Preliminary investigations on the red sea urchin resources in British Columbia [Stongylocentrotus franciscanus (Agassiz)]

Boolootian, R. A. 1966. Reproductive Physiology. In Boolootian, R. A. (editor). Physiology of Echinoderms. Interscience Publ. Wiley and Sons. pp 561 – 613.

Boolootian, R. A. and A. C. Giese. 1959. The effect of latitude on the reproductive activity of *S. purpuratus.* International Oceanographic Congress. pp 261 – 217.

Breen, P. 1980. The ecology of red sea urchins in British Columbia. Pages 3-12 in International syposium on coastal Pacific marine life. Western Washington University, Bellingham.

Breen, P. A., and B. E. Adkins. 1976. Growth rings and age in the red sea urchin, *Strongylocentrous franciscanus*. Fish. Res. Board Can. MS Rep. 1413: 17 p.

Breen, P. A., B. E. Adkins and D. C. Miller. 1978. Recovery rate in three exploited sea urchin populations from 1972 to 1977. Fish. Mar. Serv. MS Rep. 1446: 27 p.

Breen, P. A., D. C. Miller and B. E. Adkins. 1976. An examination of harvested sea urchin populations in the Tofino area. Fish. Res. Board Can. MS Rep. 1401: 23 p.

Breen, P. A., T. A. Carson, J. Bristol Foster and E. A. Stewart. 1982. Changes in Subtidal Community structure associated with British Columbia sea otter transplants. Mar. Ecol. Prog. Ser. 7: 13 – 20.

Bureau, D. 1996. Relationship between Feeding, reproductive condition, jaw size and density in the red sea urchin, *Strongylocentrotus franciscanus*. MS. Thesis. Simon Fraser University. Vancouver, BC, Canada.

Cameron R. A. and S. C. Schroeter. 1980. Sea urchin recruitment: effect of substrate selection on juvenile distribution. Mar. Ecol. Prog. Ser. 2: 246-247.

Campbell A. 1992. Size structure and gonad quality of the purple sea urchins, *Strongylocentrotus purpuratus* in southern British Columbia. PSARC Working Paper I92-13.

Campbell, A. 1998. Catch, effort and quota estimates for the red sea urchin fishery in British Columbia. In: B. J. Waddell, G. E. Gillespie and L. C. Walthers (eds.). Invertebrate working papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can Tech. Rep. Fish. Aquat. Sci. 2215: 83 - 110.

Campbell A., and R. M. Harbo. 1991. The sea urchin fisheries in British Columbia. IN Yanagisawa T., I. Yasumasu, C. Oguru, N. Suzuki and T. Motokawa (eds.) Biology of echinodremata. A. A. Balkema, Rotterdam: 191-199.

Connell, J. H. 1985. The consequences of variation in initial settlement vs. post settlement mortality in rocky intertidal communities. J. Exp. Mar. Biol. Ecol. 93: 11- 45.

Crapp, G. B. and M. E. Willis. 1975. Age determination in the sea urchin *Paracentrotus lividus* (Lamark), with notes on the reproductive cycle. J. Exp. Mar. Biol. Ecol. 20: 157 – 178.

Dayton, P. K. 1975. Experimental Studies of Algal canopy interactions in a sea otter dominated kelp commmunity at Amchitka Island, Alaska. US Natl. Mar. Serv. Fish. Bull. 73(2): 230-237.

Dixit, D. 1973. A simple technique for obtaining gametes from the purple sea urchin, *S. purpuratus*. Biosience 23(1): 39.

Duggins, D. O. 1980. Kelp beds and sea otters: An experimental approach. Ecology 61(3): 447-453.

Duggins, D. O. 1983. Starfish predation and the creation of mosaic patterns in a kelp-dominated community. Ecology 64: 1610 – 1619.

Ebert, T. A. 1967. Growth and repair of spines in the sea urchin *Strongylocentrotus purpuratus* (Stimpson). Biol. Bull. 133 (1): 141 – 149

Ebert, T. A. 1975. Growth and Mortality of post-larval echiinoids. Am. Zool. 15: 755 - 775.

Ebert, T. A. 1982. Longevity, life history, and relative body wall size in sea urchins. Ecol. Monog. 52(4): 353 – 394.

Ebert, T. A. 1968. Growth rates of the sea urchin *Strongylocentrotus purpuratus* related to food availability and spine abrasion. Ecology, 49: 1075- 1091.

Ebert, T. A. 1980. Relative growth of sea urchin jaws: An example of plastic resource allocation. Bull. Mar. Sci. 30(2): 467-474.

Ebert, T. A. 1983. Recruitment in Echinoderms. In M. Jangoux and J.M. Lawrence (editors). Echinoderm Studies. Vol. 1. A. A. Balkema, Rotterdam: 169 – 203

Ebert, T. A. 1988. Calibration of Natural growth lines in ossicles of two sea urchins, *Strongylocetrotus purpuratus* and *Echinometra mathaei*, using tetracycline. IN Burke, R. D., P. V. Mladenov, P. Lambert, and R. L. Porsley.(eds.) Echinoderm biology. A. A. Balkema Rotterdam: 435 – 448.

Ebert, T. A. and M. P. Russell. 1988. Latitudinal variation in the size structure of the west coast purple urchin: a correlation with headlands. Limnol. Oceanogr. 33(2). 286 – 294.

Ebert, T. A., S. C. Schroeter and J. D. Dixon. 1998. An analysis of the importance of Allee effects in management of red sea urchins: Differences between Oregon/Washington and southern California. Taking a Look at California's Ocean Resources: An Agenda for the Future, ASCE, Reston, VA (USA) vol. 1, p. 425.

Ebert, T. A., S. C. Schroeter, J. D. Dixon and P. Kalvass. 1994. Settlement patterns of red and purple sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus*) in California, USA. Mar. Ecol. Prog. Ser. 111:41-52.

Edmands S., P. E. Moberg, and R. S. Burton. 1996. Allozyme and mitochondrialk DNA evidence of population subdivision in the purple sea urchin *Strongylocentrotus purpuratus.* Mar. Biol. 126: 443 – 450.

Edwards P. B. and T. A. Ebert. 1991. Plastic responses to limited food availability and spine damage in the sea urchin *Strongylocentrotus purpuratus* (Stimpson). J. Exp. Mar. Biol. Ecol. 145: 205 – 220

Estes, J. A. N. S. Smith and J.F. Palmisano. 1978. Sea otter predation and community organization in the western Aleutian Islands, Alaska. Ecology 59: 822 – 833.

Farmanfarmaian, A. and A. C. Giese. 1963. Thermal tolerance and acclimation in the western purple sea urchin, *Strongylocentrotus purpuratus*. Physiol. Zool. 36: 237 - 243.

Fuseler, J. W. 1973. Repetitive procurement of gametes from individual sea stars and sea urchins. J. Cell. Biol. 57(3): 879 – 881.

Gage, J. D. 1991. Skeletal growth zones as age markers in the sea urchin *Psammechinus miliaris*. Mar. Biol. 110: 217 – 228.

Gage, J. D. 1992. Natural growth bands and the growth variability in the sea urchin *Echinus esculentus*: Results from tetracycline tagging. Mar. Biol. 114: 607 – 616.

Gaines, S. and J. Roughgarden. 1985. Larval settlement rate: A leading determinant of structure in an ecological community of the marine intertidal zone. Proc. Natl. Acad. Sci. 82: 3707-3711.

Gaines, S., and J. Roughgarden. 1985. Larval settlement rate: A leading determinant of structure in an ecological community of the marine intertidal zone. Proc. Natl. Acad. Sci. 82: 3707 – 3711.

Gilles, K.W. and J.S. Pearse. 1986. Disease in sea urchins strongylocentrotus purpuratus: experimental infection and bacterial virulence. Dis. Aquat.Org. 1: 105 – 114.

Gillespie, G. E. 1997. Review of biology, fisheries and assessment of oceanic squids, particularly *Ommastrephes bartrami, Onychoteuthis borealijaponica, Gonatopsis borealis and Berryteuthis magister*. Canadian stock assessment secretariat research document 97/143: ii + 46 p.

Gillespie, G. E. 1999. Stock assessment and Management frameworks for the proposed fishery for the sea mussels (*Mytilis californianus*) in British Columbia. Canadian stock assessment secretariat research documentI 99/116: ii + 31 p.

Gillespie, G. E., G. Parker and J. Morrison. 1998. A review of octopus fishery biology and British Columbia octopus fisheries. Canadian stock assessment secretariat research document 98/87: iv + 63 p.

Gonor, J. J. 1972. Gonad growth in the sea urchin, *Strongylocentrotus purpuratus* (Stimpson) (Echinodermata:Echinoidea) and the assumptions of gonad index methods. J. Exp. Mar. Biol. Ecol. 10: 89 – 103.

Gonor, J. J. 1973a. Reproductive cycles in Oregon popularions of the echinoid, *strongylocentrotus purpuratus* (Stimpson). I. Annual gonad growth and ovarian gametogenetic cycles, J. Exp. Mar. Biol. Ecol. 12: 45 – 64.

Gonor, J. J. 1973b. Reproductive cycles in Oregon popularions of the echinoid, *Strongylocentrotus purpuratus* (Stimpson). II. Seasonal changes in oocte growth and in abundance of gametogenic stages in the ovary. J. Exp. Mar. Biol. Ecol. 12: 65 – 68.

Gulland, J. A. 1974. The management of marine fisheries. Univ. Wash. Press, Seattle, 198 p.

Haaker, P. L., G. E. Davis and I. K. Taniguchi. 1996. Serial Depletion in marine invertebrate diving fisheries. J. Shellfish Research 15(2): 526

Harrold, C. and J. S. Pearse. 1987. The ecological role of echinoderms in kelp forests. In M.Jangoux, J.M. Lawrence. eds. Echinoderm studies A. A. Balkema, Rotterdam: 137 – 233.

Harvey, E. B. 1954. Electrical methods of determining the sex of sea urchins. Nature (London) 173: 86.

Heizer, S., G. Thomas, and K. Hobbs. 1997. Red sea urchin dive fishery update. Can. MS. Rep. Fish. Aquat. Sci. 2369: 93 – 102.

Himmelman, J. H. A. Cardinal and E. Bourget. 1983. Community development following removal of urchins Strongylocentrotus droebachiensis, from the rocky subtidal zone of the St. Lawrence estuary, Eastern Canada. Oecologia 59: 27 – 39.

Hinegardner, R. T. 1969. Growth and development of the laboratory cultured sea urchin. Biol. Bull. 137: 465 – 475.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. , U. S. 81: 898 – 903.

Jangoux, M. 1987. Diseases of echinodermata I. Agents microorganisms and protistans. Dis. Aquat. Org. 2: 147 – 162.

Jensen, M. 1969. Age determination in Echinoids. Sarsia 37: 41 – 44.

Johnson, C. R. and K. H. Mann. 1982. Adaptation of *Strongylocentrotus droebrtachiensis* for survival on barren grounds in Nova Scotia. IN Lawrence J. M. (ed.) International Echinoderm Conference, Tampa, Bay. A. A. Balkema, Rotterdam. 277 – 283.

Johnson, P.T. 1971. Studies on diseased urchins from Pt. Loma. In. North, W. J. (ed.) Kelp habitat improvement project , annual report 1970-1971. California Institute of Technology, Pasadena, p. 82 – 90.

Jones, G. M., and R. E. Scheibling. 1985. *Paramoeba* sp. (Amoebida, Paramoebidae) as the possible causative agent of sea urchin mass mortality off Nova Scotia. J Parasitol. 71: 559 – 565.

Kalvass, P. E. and Jon M. Hendrix. 1997. The California red sea urchin, *Strongylocentrotus franciscanus*, Fishery: Catch, effort, and management trends. Mar. Fish. Rev. 59(2): 1 – 17.

Kato, S. and S. C. Schroeter. 1985. Biology of the red sea urchin *Strongylocentrotus franciscanus*, and its fishery in California. Mar. Fish. Rev. 47 (3): 1 – 20.

Kawamura, K. 1973. Ezobafun uni no gyogyo seibutsugakuteki kenku (Fishery biological studies on the sea urchin S. intermediius (A. Agassiz), with english summary). Hokkkaidoritsu suisan shikenjo Hokoku 16: 1-54.

Kenner, M. C. 1992. Population Dynamics of the sea urchin *Strongylocentrotus purpuratus* in a central Califoirnia kelp forest: Recruitment, mortality, growth and diet. Mar. Biol. 112: 107 – 118.

Kenner, M. C. and M. T. Lares. 1991. Size at first reproduction of the sea urchin *Strongylocentrotus purpuratus* in a Central California kelp forest. Mar. Ecol. Prog. Ser. 76: 303 – 306.

Koshida, Y. 1973. Practical application of acetylcholine method as a non-injurious means to obtain eggs from sea urchins. Publ. Seto Mar. Biol. Lab. 21(2): 95 – 98.

Kozloff, E. N. 1974. Keys to the marine invertebrates of Puget Sound, the San Juan Archipelago and adjacent regions. University of Washington Press, Seattle and London.

Kramer, D. E. and D. M. A. Nordin. 1975. Physical data from a study of size, weight and gonad quality for the red sea urchin, *Strongylocentrotus franciscanus* (Agassiz) over a one-year period. Fish. Res. Board Can. MS Rep. Series 1372. Iv + 90 p.

Kramer, D. E. and D. M. A. Nordin. 1979. Studies on the Handling and Processing of sea urchin Roe. I. Fresh product. Fish. Mar. Serv. Tech. Rep. 870. vii + 47 p.

Krause, G. G. 1995. Strategy for the development of a purple urchins fishery in British Columbia. IEC Collaborative Marine Research and Development Ltd. 146 Regina St. Victoria, BC.

Krause, G. G. 1996. British Columbia Purple Urchin Association (BCPUA), Survey Report. IEC Collaborative Marine Research and Development Ltd. 146 Regina St. Victoria, BC.

Lasker R. and A. C. Giese. 1954. Nutrition of the sea urchin, *S. purpuraus.* Biol. Bull. (Woods Hole) 106(3): 328 – 340.

Lauzier, R. B. 1997. A review of the biology of the milky venus clam (*Compsomyax subdiaphana*) and the fisheries of related subtidal species. Canadian stock assessment secretariat research document 97/136: vi + 33 p.

Lauzier, R. B. 1999. A review of the biology and fisheries of the goose barnacle (*Pollicipes polymerus* Sowerby, 1833). Canadian stock assessment secretariat research document 99/111: iv + 23 p.

Lauzier, R. B., C. M. Hand, A. Campbell and S. Heizer. 1998. A review of the biology and fisheries of horse clams (*Tresus capax and Tresus nuttallii*). Canadian stock assessment secretariat research document 98/88 v + 28 p.

Lawrence, J. M., A. L. Lawrence and N. D. Holland. 1965. Annual cycle in the size of the gut of the purple sea urchin, *S. purpuratus* (Stimpson). Nature (London) 205: 1238 – 1239.

Lawrence, J. M. 1975. On the relationship between marine plants and sea urchins. Oceanogr. Mar. Biol. Ann. Rev. 13: 213 – 286.

Lawrence J. M., and P. W. Samarco. 1982. Effects of feeding on the environment: echinoidea. In M. Jangoux and J. M. Lawrence, eds. Echinoderm nutrition. A. A. Balkema, Rotterdam. 499 – 519.

Lai, H-L., and A. Bradbury. 1998. A modified catch at size model for red sea urchins (*Strongylocentrotus franciscanus*) population. IN Jamieson G. S. and A. Campbell (eds). Proceedings of the North Pacific symposium on invertebrate stock assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125. 85 – 96.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bull. Ent. Soc. Am. 15: 237 – 240.

Levitan D. R., M. A. Sewell and F. Chia. 1992. How distribution and abundance influence fertilization success in the sea urchin *Strongylocentrotus franciscanus*.

Levitan, D. R. 1988. Density dependant size regulation and negatives growth in the sea urchin *Diadema antillarum* Philippi. Oecologia 76: 627 – 629.

Levitan, D. R. 1991. Influence of body size and population density on fertilization success and reproductive output in a free-spawning invertebrate. Biol. Bull. 181: 261 – 268.

Lewis, C. A., T. A. Ebert and M.E. Boren. 1990. Allocation of ^{45}calcium to body components of starved and fed purple sea urchins, *Strongylocentrootus purpuratus*. Mar. Biol. 105: 213 – 222.

Mackinson, S., and L. Nottestad. 1998. Combining local and scientific knowledge. Rev. Fish Biol. and Fish. 8: 481 – 490.

McCauley, J. E. and A.G. Carey, Jr. 1967. Echinoidea of Oregon. J. Fish. Res. Board Can. 24: 1385 – 1401.

Maes, P., M. Jangoux, and L. Fenaux. 1985. La maladie de l'oursin-chauve: Ultrastructure des lesions et caracterisation de leur pigmentation. Annls. Inst. oceanogr., Paris.

Mead K. S. and M. W. Denny. 1995. Th effects of hydrdynamic shear stress on fertilization and early development on the purple sea urchin *Strongylocentrotus purpuratus*.

Morris R. H., D. P. Abbottt and E. Haderlie, 1980. Intertidal invertebrates of California. Stanford University Press. ix + 690 p.

Mottet, M. G. 1976. The fishery biology of sea urchins in the family strongylocentrotidae. Wash. Dep. Fish. Tech. Rep. 20: 1-66.

Okada, K. and Y. Miyauchi. 1954. Normal table of the early developmental stages of the sea urchin, *Hemicentrotus pulcherrimus*. Tokushima Gakugei Daigaka Kenkyo Hokoku 5: 57-68.

Paine R. T. and R.L. Vadas. 1969. The effect of grazing by sea urchins Strongylocetrotus spp. on benthic algal populations. Limnol. Oceanogr. 14: 710 – 719.

Paine, R. T. 1986. Benthic Community-water column coupling during the 1982-1983 El Nino. Are community changes at high latitudes attributable to cause or coincidence? Limnol. Oceanogr. 31(2): 351 – 360.

Parish, R. H., C. S. Nelson and A. Bakun. 1981. Transport mechanisms and reproductive success of fishes in the California Current. Biol. Oceanogr. 1: 175 – 203.

Parrish, R. H., C. S. Nelson and Bakun. 1981. Transport mechanisms and reproductive success of fishes in the California current. Biol. Oceanogr. 1: 175 - 203.

Pearse J. S. and A. H. Hines. 1987. Long-term population dynamics of sea urchins in a central California kelp forest: Rare recruitment and rapid decline. Mar. Ecol. Prog. Ser. 39: 257 – 283.

Pearse J. S., V. B. Pearse and K. K. Davis. 1986. Photopperiodic regulation of gametogenesis and growth in the sea urchin Strongylocentrotus purpuratus. J. Exp. Zool. 237: 107 – 118.

Pearse, J. S. and V. B. Pearse. 1975. Growth zones in the Echinoid Skeleton. Am. Zool. 15: 731 – 753.

Perry, R. I., B. J. Waddell, A. Campbell, and K. Hobbs. 1998. Review of fishery-dependant data and quota recommendations for 1995/96 for the green sea urchin fishery in British Columbia. IN: B. J. Waddell, G. E. Gillespie and L. C. Walthers (eds.). Invertebrate working papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can Tech. Rep. Fish. Aquat. Sci. 2215: 111 –1 46.

Perry, R. I., C. J. Walters and J. Boutillier. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. Rev. Fish Biol. Fish.. 9: 125-150.

Phillips, A. C. and R. Lauzier. 1997. Biological background foir the development of a new fishery for the grooved tanner crab (*Chionoecetes tanneri*) of British Columbia. Canadian stock assessment secretariat research document 97-148: 81 p.

Pleschner D. B. 1992. Purple Rage. Pacific Fishing. January 1992.

Ricketts E. F. and J. Calvin. 1939. Between Pacific tides. Stanford Univ. Press. xii + 516 p.

Richmond, N., J. Schaefer, C. Wood and J. McCrae. In Press. History and Status of the Oregon urchin fishery, 1986 – 1996. 24 p.

Robinson, S. M. C. and A. D. MacIntyre. 1997. Aging and growth of the green sea urchin. Bull. Aquacul. Assoc. Canada 97: 56 – 60.

Russel, M. P. 1987. Life history traits and resource allocation in the in the purple sea urchin *Strongylocentrotus purpuratus*(Stimpson). J. Exp. Mar. Biol. Ecol. 108: 199 – 216.

Scheibling, R. E. 1984. Succession of macroalgea following mass mortalities of *Strongylocentotus droebachiensis* off Nova Scotia, Canada. In B. F. Keegan, and B. D, O'Connor (eds). Echinodermata. A. A. Balkeema, Rottrerdam. 395.

Scheibling R. E. and A. W. Hennigar. 1997. Reciurrent outbreaks of disease in sea urchins *Strongylocentrotus droebachiensis* in Nova Scotia: evidence for a link for large-scale meteorological and oceanographic events. Mar. Ecol. Prog. Ser. 152: 155-165.

Schroeter S. C., J. D. Dixon, T. A. Ebert and J.V. Rankin. 1996. Effects of Kelp Forests *Macrocystis pyrifera* on the distribution and settlement of red and purple sea urchins *Strongylocentrotus franciscanus* and *S. purpuratus*. Mar. Ecol. Prog. Ser. 133: 125- 134.

Schroeter, S. C. 1978. Experimental studies of competition as a factor affecting the distribution and abundance of purple sea urchins, *Strongylocentotus purpuratus* (Stimpson) Ph. D. thesis, University of California, Santa Barbara.

Scott F. H. 1902. Food of the sea urchin (*Stongylocentrotus drobachiensis*). J. Fish. Aquat. Sci. 1: 49 – 54

Sloan, N. A., C. P. Lauridsen and R. M Harbo. 1987. Recruitment characteriistics of the commercially harvested red sea urchin *Strongylocentrotus franciscanus* in southern British Columbia, Canada. Fish. Res. 5: 55-69.

Steele B and D. B. Plescher. 1991. How to pick pack and live ship purple sea urchins. EPA Contract Report no. A900-181: i + 14 p.

Stephens, P. A. and W. J. Sutherland. 1999. Consequences of the Allee efect for behavior, ecology and conservation. Trends Ecol. Evol. 14 (10): 401-405.

Strathmann, R. 1971. The feeding behavior of plankton echinoderm larvae: Mechanisms, regulation, and rates of suspension feeding. J. Exp. Mar. Bio. Ecol. 6(2): 109 – 160.

Strathmann. R. 1978. Length of Pelagic period in echinodrems with feeding larvae from the northeast pacific. J. Exp. Mar. Biol. Ecol. 34: 23 – 27.

Swan, E. F. 1961. Some observations on the growth rate of sea urchins in the genus Stongylocentrotus. Biol. Bull. 120: 420 – 427.

Tajima, K., K. Takeuchi, M. M. Iqbal, K. Nakano, M. Shimizu, and Y. Ezura. 1998. Studies on a bacterial disease of sea urchins Strongylocentrotus intermedius occuring at low water temperatures. Fish. Sci. 64(6): 918 – 920.

Tegner M. J. and P. K. Dayton. 1981. Population structure, recruitment and mortality of two sea urchins (*Strongylocentrotus franciscanus, S. purpuratus*) in a kelp forest. Mar. Ecol. Prog. Ser. 5: 255 – 268.

Tegner, M. J. 1989. The feasibility of enhancing red sea urchin, *Strongylocentrotus franciscanus,* stocks in Cailifornia: An Analysis of the options. Mar. Fish. 51: 1 – 22.

Tegner, M. J. and P. K. Dayton. 1977. Sea urchin recruitment patterns and implications of commercial fishing Science, Wash. D. C. 196: 324-326

Thomson, R. E. 1981. Oceanographyb of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56.

Thomson, R. E., B. M. Hickey and P. H. LeBlond. 1989. The Vancouver Island Coastal current: fisheries barrier and conduit, p. 265 – 296. IN R. J. Beamish and G. A. McFarlane (eds). Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Vadas, R. L. 1977. Preferential feeding: an optimization strategy in sea urchins. Ecol. Monog. 47: 337 – 371.

Vélez-Andrade, L. V., and O. Sosa-Nishizaki. 1998. Some biological Aspects of the purple sea urchin, *Strongylocentrotus purpuratus* from Todos Santos Island, B.C., Mexico.Poster.
http://www.calacadamy.org/research/izg/echinoderm/conference/abst219.htm

Waddell B. J., R. I. Perry, G. Scharf and G. Ross. 1997. Surveys on the green sea urchin (*Strongylocentrotus droebachiensis*) populations in Queen Charlotte Strait, British Columbia, October 1995 and March 1996. Can. Tech. Rep. of Fish. Aquat. Sci. 2143: vii + 36 p.

Watson, J. C. 1993. The Effects of sea otter (*Enhydra lutris*) foraging on shallow rocky communities off northwestern Vancouver Island, British Columbia. Ph. D. Thesis, University of California, Santa Cruz.

Woodby, D. 1992. Red sea urchins in Alaska: Status of research and management. IN The management and enhancement of sea urchins and other kelp bed resources: A Pacific rim perspective. Calif. Sea. Grant rep. T-CSGCP-028. Univ. Calif. La Jolla. 70 – 81.

Yui M. A. and C. J. Bayne. 1983. Echinoderm immunology: Bacterial clearance by the sea urchin *Strongylocentrotus purpuratus*. Biol. Bull. 165: 473 – 486.

1.

Table 1 . Annual landings of sea urchins (in thousands of pounds) by state or province. All 1997 data are preliminary. Table from the Pacific Marine States Fishery Commision Annual report for 1997 available on the world wide web at http://www.psmfc.org/ann_rpt/1997/urchin-alba.html#SEAURCHINFISHERY Updated with catch figures where available.

Year	Alaska	British Columbia	Wash-ington	Oregon	California	Total
1971		**	1.8		0.2	2.0
72		**	2.5		76.5	79.0
73		802.5	14.7		3,594.7	4,411.9
74		†	57.4		7,107.8	7,165.2
75		†	31.0		7,567.2	7,598.2
76		†	1,544.4		11,106.4	12,650.8
77		154.5	1,045.6		16,536.3	17,736.4
78		165.3	471.4		14,424.3	15,061.0
79		701.5	697.0		20,544.2	21,942.7
1980	*	733.7	132.9		22,167.1	23,033.7
81	*	254.2	304.2		26,333.7	26,892.1
82	*	351.2	40.6		18,403.9	18,795.7
83	*	2,173.3	497.2		15,809.4	18,479.9
84	107.4	3,890.1	604.5		14,746.5	19,348.5
85	126.0	4,001.2	878.8		19,994.9	25,000.9
86	282.4	4,556.7	3,501.2	55.8	34,130.7	42,526.8
87	757.1	4,935.0	4,908.3	202.8	45,636.8	56,440.0
88	244.9	5,644.5	9,357.9	1,947.3	51,988.0	69,182.6
89	187.0	7,201.2	5,739.7	7,842.6	51,187.3	72,157.8
1990	100.3	8,008.5	6,839.2	9,320.9	45,269.7	69,538.6
91	225.1	16,105.2	5,686.4	4,736.9	41,926.7	68,680.3
92	454.1	30,917.8	3,298.2	2,954.2	32,681.4	70,305.7
93	368.9	15,378.9	1,867.6	2,217.3	27,012.4	46,845.1
94	23.4	13,582.0	2,037.9	1,986.7	23,985.0	41,615.0
95	2,118.2	14,689.9	1,036.2	1,546.2	22,316.9	41,707.5
96	933.3	14,143.8	1,223.5	819.5	20,120.4	37,240.5
1997	6,527.0	12,644.3	1,048.1	490.1	18,018.7	38,728.1

* Confidential information: fewer than four fishermen with landings

** Data from 1971 to 1973 combined

† Data from 1974 to 1977 combined

Table 2: Purple urchin pre-harvest density, mean size, and percent sub-legal from commercial diver surveys in Oregon (from Richmond et al., In press)

Area	Density	Mean size	Percent < 51 mm	Quota Estabilshed
N. Depoe mBay	108	64	2.1	100,000 (45 t)
S Depoe Bay	72	66	13.4	100,000 (45 t)
S of Shell Cove	49	61	8.3	100,000 (45 t)
Cape foulweather	51	51	42.5	0
Gull Rock	114	66	5.6	50,000 (22.5 t)
Arago Lighthouse	164	74	11.5	0
Sunset Bay	185			0
Simpson Reef A	148	69	16.4	130,000 (59 t)
Simpson Reef A2	124	69	16.9	
Simpson Reef B	135	64	26.1	
Arago X	93	61	10.9	75,000 (34 t)
Arago C	60	69	9.0	30,000 (13.6 t)
Cape Blanco	128	64	27.8	10,000 (4.5 t)
Klooqueh Rock	112	61	26.9	10,000 (4.5 t)

Table 3: Landed weight of Purple Sea urchins in the California, Oregon and BC purple sea urchin fisheries. The Oregon data are from Richmond et al. in press, the California data was provided by Peter Kalvass, California Department of Fish and Game, and the British Columbia catch data is from the DFO shellfish commercial sales slip database at the Pacific Biological Station.

Year	California		Oregon		BC	
		Kg	Lb	Kg	Lb	Kg
1989	1,500	680	Nil			
1990	89,600	40642	Nil		1488	675
1991	388,000	175994	Nil		917	416
1992	316,100	143381	96883	43945	122241	55463
1993	165,000	74843	34235	15529		
1994	137,600	62414	197109	89407		
1995	81,400	36922	42359	19214		
1996	55,700	25265	675	306		
1997	122,000	55338	310	141		
1998	14,100	6396	3768	1709		

Table 4: Summary of landed weights by Fishing year, Management Statistical Area and vessel. These data are summarized from the shellfish historic sales slip database. These data are from keypunched sales slips received from processors.

Fishing_year	AreaCode	1	2	3	4	5	6	7	Grand Total
89	240						675		675
90	190	60		104	252				416
91	120		503						503
91	200		14428	9541	10470			19554	53993
91	240					967			967
Grand Total		60	14931	9644	10722	967	675	19554	61935

Table 5: Total catch weight in kilograms, dive time in minutes and diver days required to log those minutes. These data are summarized from fisher logs. Localities are best approximations from the logs and maps submitted.

		Year			
Locality	Data	89	90	91	Grand Total
Estevan Pt.	Total catch weight			1286	1286
	Dive time			665	665
	Diver days			4	4
Port san Juan	Total catch weight			1771	1771
	Dive time			605	605
	Diver days			8	8
Sombrio Pt.	Total catch weight	181	475	57575	58233
	Dive time	60	390	14075	14525
	Diver days	1	18	196	215
Sooke	Total catch weight			2024	2024
	Dive time			895	895
	Diver days			20	20
Total catch weight		181	475	62657	63315
Dive time		60	390	16240	16690
Diver days		1	18	228	247

Table 6: Summary of size frequency and density data of *S. purpuratus* collected subtidally (3-14 m) with 1 m^2 quadrats on the south-west coast of Vancouver Island. Data collected by a = fishers, b = DFO personnel, c = after Kramer and Nordin (1975, Appendix C). Legal size = 55 mm test diameter. *Includes Feb 8/92. (From Campbell, 1992)

			Test diamter				%		Density
Location	MSA	Date	Mean	Median	Min	Max	< 55mm	N	n/m2
Albert head	19	01-Oct-74	79	81	48	104	2	100	"-"[c]
Sombrio	20	18-Apr-90	52	53	28	70	63	511	49-105[a]
Sombrio	20	24-Nov-91	70	70	48	92	2	163	6-25[a]
Botanical Beach	20	03-Dec-91	59	59	33	72	24	187	7-27[a]
Barkley Sound	23	29-Jan-90	62	62	43	86	16	459	9-80[a]
Amphitrite Point	23	16-Dec-89	63	63	48	87	9	137	10-130[a]
Wickaninnish Island	24	24-May-90	59	61	19	99	27	348	4-41[b]
Tofino	24	13-Dec-90*	69	68	50	88	2	304	3-49[a]

Table 7: Summary of size frequency of port samples of *S. purpuatus* collected subtidally (3-14 m) on south-west Coast of Vancouver Island during the 1991-1992 fishing season. Legal size = 55 mm test diameter, N = total number

				Test diamter			%		g per
Location	MSA	Date	Mean	Median	Min	Max	< 55 mm	N	Urchin
Sooke	20	23-Feb-91	68.1	68	49	85	8.7	92	
Botanical Beach	20	03-Dec-91	63.9	64	50	80	5	201	105
Sombrio Point	20	18-Dec-91	67.6	68	46	86	1.5	805	120
Sombrio Point	20	08-Jan-92	61.1	61	44	88	13.9	800	97
Sombrio Point	20	01-Feb-92	62.7	62	47	79	5.9	800	108
Sombrio Point	20	13-Apr-92	67.7	68	50	84	0.5	200	

Table 8: Numbers of *Strongylocentrotus purpuratus* harvested by scientific supply companies each year in BC. Data are from the DFO, South Coast Division, scientific collection permit database.

Company	Year	Scientific Name	Common name	Number	Units
Seacology	1996	*Strongylocentrotus purpuratus*	purple sea urchin	180	Pieces
Seacology	1997	*Strongylocentrotus purpuratus*	purple sea urchin	584	Pieces
Seacology	1998	*Strongylocentrotus purpuratus*		175	Pieces
Seacology	1999	*Strongylocentrotus purpuratus*		425	Pieces
Vancouver Aquarium	1997	*Strongylocentrotus purpuratus*	Purple sea urchin	5	Pieces
Vancouver Aquarium	1998	*Strongylocentrotus purpuratus*	purple-sea urchin	5	Pieces
WestWind	1996	*Strongylocentrotus purpuratus*	purple sea urchin	120	Pieces
WestWind	1997	*Strongylocentrotus purpuratus*	purple sea urchin	1154	Pieces
Westwind	1998	*Strongylocentrotus purpuratus*	Purple sea urchin	1215	Pieces
UBC	1999	*Strongylocentrotus purpuratus*	Purple sea urchin	300	Pieces

Table 9. Summary of the status of biological knowledge for *S. purpuratus*. Lowercase roman numerals indicate questions relevant to the category, they are addressed by numbered responses.

Population structure and unit stock size	i. is the species sessile, sedentary, mobile, or pelagic and highly mobile? ii. what is a characteristics spatial scale for adult movements? iii. are there substantial seasonal migrations (horizontal or vertical)? iv. are the aggregations likely to be part of a larger meta-population? v. What is a possible geographic scale for a unit stock? 1. Intertidal *S. purpuratus* are reasonably sedentary moving tens or hundreds of meters in a lifetime, subtidaly they may undertake modest spawning or feeding migrations. 2. The species does not undertake significant seasonal migrations but will form spawning aggregation to improve fertilization success. 3. The species does form aggregation as a defensive strategy against predators. 4. The species occurs in small discrete patches of 1 to a few meters in area. 5. This species is a classic example of a meta-population with free spawning adults and a protracted larval stage of 2 – 3 months indicating the entire population from Point Conception northward could constitute one stock
Distribution	i. What is the known geographic range for the species? ii. is the area proposed for fishing at the geographic extremes, or in the centre, of the known range? iii. What is the known depth distribution of the species? iv. do individuals aggregate into high density patches, or do they tend to be solitary? 1. The geographic range is from Baja Caliornia to Sitka, Alaska. 2. The proposed fishery is near the center of the animal's geographic range but probably near the northern extreme for a fishable stock 3. The species is common in the inter-tidal down to 3 m but has been found as deep as 160 m.
Preferred habitats	i. identify habitat characteristics of high density and low density aggregations, e.g. bottom type, sediment features, hydrographic features (temperature, salinity, oxygen concentration), current and water circulation features ii. important or critical associations with other species? 1. The preferred habitats of *S. purpuratus* are exposed wave swept rocky shores with temperature in the range of 5 – 23 degrees C, salinities of 28 ppt to 38.5 ppt and high levels of dissolved oxygen. 2. As part of the kelp forest community critical species associations

	include the dominat predators: Sea otters and Sunflower stars, and the prefferred prey or the purple sea urchin: *Macrocystis pyrifera* and *Nereocystis luetkeana*.
Size of population	i. Estimates of potential population size, in particular on relevant spatial scales 1. The potential population size is unknown in BC, given the abundance of potential habitat and food there may be substantial populations on the exposed coastline. Unpublished observations indicate the distribution in BC varies from patchy to continuous and from highly aggregated to dis-aggregated.
Size/age structure (lifespan)	i. can ages be determined? ii. Relationships of size with age, or ability to distinguish size classes that may relate to age iii. Potential maximum life span iv. age/size structure of populations, preferably on relevant spatial scales (i.e. many old or larger individuals) v. sexual dimorphism in body; young individuals; spatial segregation by age? vi. sex ratio; hermaphroditism? features (e.g. size)? 1. The ages of urchins cannot be reliably determined, current research underway hold promise for improved aging in urchins (B. Campbell pers. comm.) 2. The relationship between size and age is variable and controlled by external forces such as the availability of food and the degree of physical abuse the animal is exposed to. Animals reach about 40 mm Test diameter and sexual maturity after 3 years of life under normal conditions. 3. The estimated maximum age of purple sea urchins is greater than 50 years. 4. The age composition of local purple urchin stocks is unknown. Size composition data tends to be skewed towards larger individuals because the larger size classes represent an accumulation of multiple older age classes. Given the size composition of *S. purpuratus* harvested in Sombrio in 1992 it is likely that the harvest was composed primarily of older urchins. 5. There appears to be no segregation by age class reported in the literature, anecdotal reports indicate juveniles may recruit from depth.
Reproductive characteristics	i. Broadcast spawner; egg-brooding; parental care of young? ii. egg and larval duration (potential for transport by currents and the possible range) iii. for broadcast spawners - critical minimum density for spawning? iv. fecundity-at-size/age

	1. Purple sea urchins are broadcast spawners. Unlike *S. fransiscanus* the shorter spine of *S. purpuratus* afford less opportunity for purple urchins to shelter their offspring. 2. Eggs mature into echinoplute larvae in 2 – 4 days under laboratory conditions. The larval period is protracted lasting at least 2 to 3 months 3. Fertilization success is directly dependent on spawner density, separation by more than 10 cm greatly reduces fertilization success. There is the potential for Allee effects with this species. 4. Fecundity is directly proportional to size and very high. 5. Size at first maturity can be reduced under conditions of extreme predation.
Productivity characteristics	i. growth rates - by life history stage (juvenile, adult) and by spatial scale ii. Growth characteristics - e.g. step-wise growth and molting of crustaceans? iii. Mortality rates – spatially explicit? iv. Recruitment rates, and identification of potential source and sink aggregations for meta-populations? 1. Growth as juveniles is rapid with most individuals attaining 80 –90 % of their asymptotic size after the first 4 years. 2. Growth rate varies throughout the year being highest between July and December, lowest between January and March and intermediate from march to July. 3. Mortality rates for BC appear to be in the range of 0.09 – 0.11, mortality appears to be higher in the southern latitude. 4. Recruitment is variable being driven by small and large-scale oceanographic events.
Fishing techniques	i. proposed gears, seasons? ii. selectivity of the gear- high (e.g. hand-picking by divers), poor (e.g. trawls and drag nets)? iii. potential for natural refuges (combination of gear capabilities and preferred habitats)? iv. potential for survival after capture and release? 1. The proposed harvest method for this fishery is hand picking by divers, the method is both size and species selective, there is little or no potential for bycatch 2. Potential natural refuges would include the intertidal zone (if harvest is limited to subtidal populations) and marine parks and marine protected areas (MPA).
Habitat disturbances	• analyses of fishing techniques, habitat characteristics, and species associations to estimate potential habitat and ecosystem disturbances of fishing

	• The potential impact of fishing on the physical habitat of purple sea urchins is negligible, the potential impact to the ecosystem is significant in that increased algal abundance as a result of harvest may positively affect other species. Conversely, the importance of this species to Sea otters is significant thus harvest may adversely effect their recovery on the BC coast.
Fisheries experiences	• discussion of fisheries and management practices for the species elsewhere - what worked, what did not, and why? • The experience elsewhere harvesting this species else where has not met with great success, the shorter harvest window and small size of the purple sea urchin make it more difficult to market than the larger red sea urchin.
Potential management strategies	i. what are the potential management strategies that might be proposed for this species (based on the characteristics above), and what are the scientific information needs for each strategy? 1. The potential management strategies for this species should include quotas, size limits, area and seasonal closures, a rotational fishery and license limitation. 2. To apply size limits successfully we need to gather more data on the size a first maturity and, growth rates in BC waters. The size limit imposed during the permit fishery (55mm) was probably effective at ensuring several spawnings prior to harvest but this needs to be confirmed. 3. To compute quotas we will need an estimate of standing stock or virgin biomass. It is possible that quotas could be assigned on a bed by bed basis but this is likely to prove too expensive. A more practical approach would be to compute quotas by MSA and rotate the fishery among MSA allowing several years for reassessment of an area prior to re-harvest. In addition further work would be required to refine estimates natural mortality in BC for sub-tidal populations of *S. purpuratus.* Rotational closures combined with license limitation at the outset would effectively limit effort and reduce the possibility of a gold rush fishery from taking place.

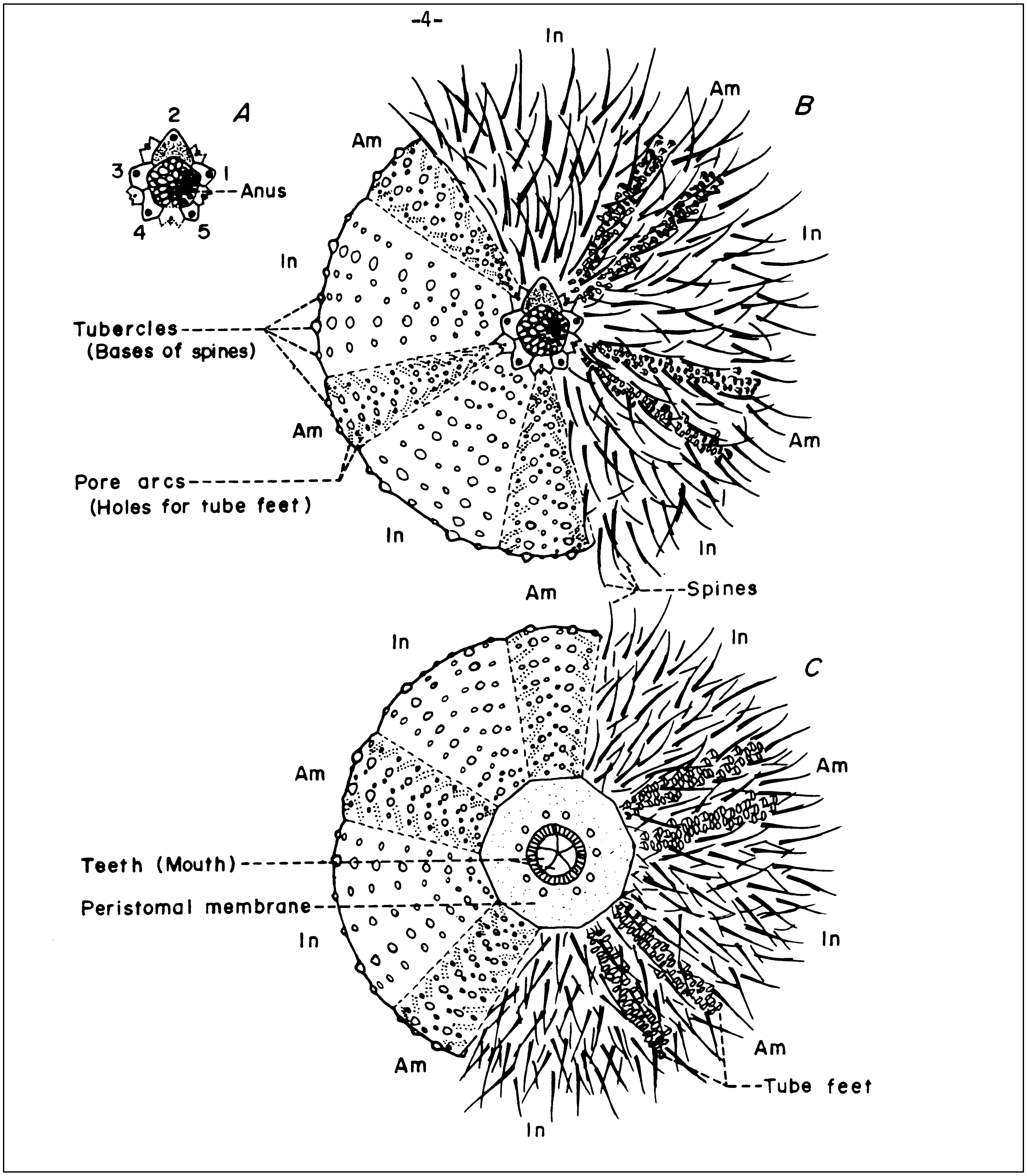

Figure 1. External anatomy of a sea urchin based on a specimen of Strongylocentrotus purpuratus. **A** shows the numbering of the genital plates. The plates indicated by dotted lines are ocular plates. **B** is the top or aboral view of the sea urchin. **C** is the bottom or oral side. The five ambulacral and interambulacral areas are indicated by an Am or In, respectively. (Mottet, 1976)

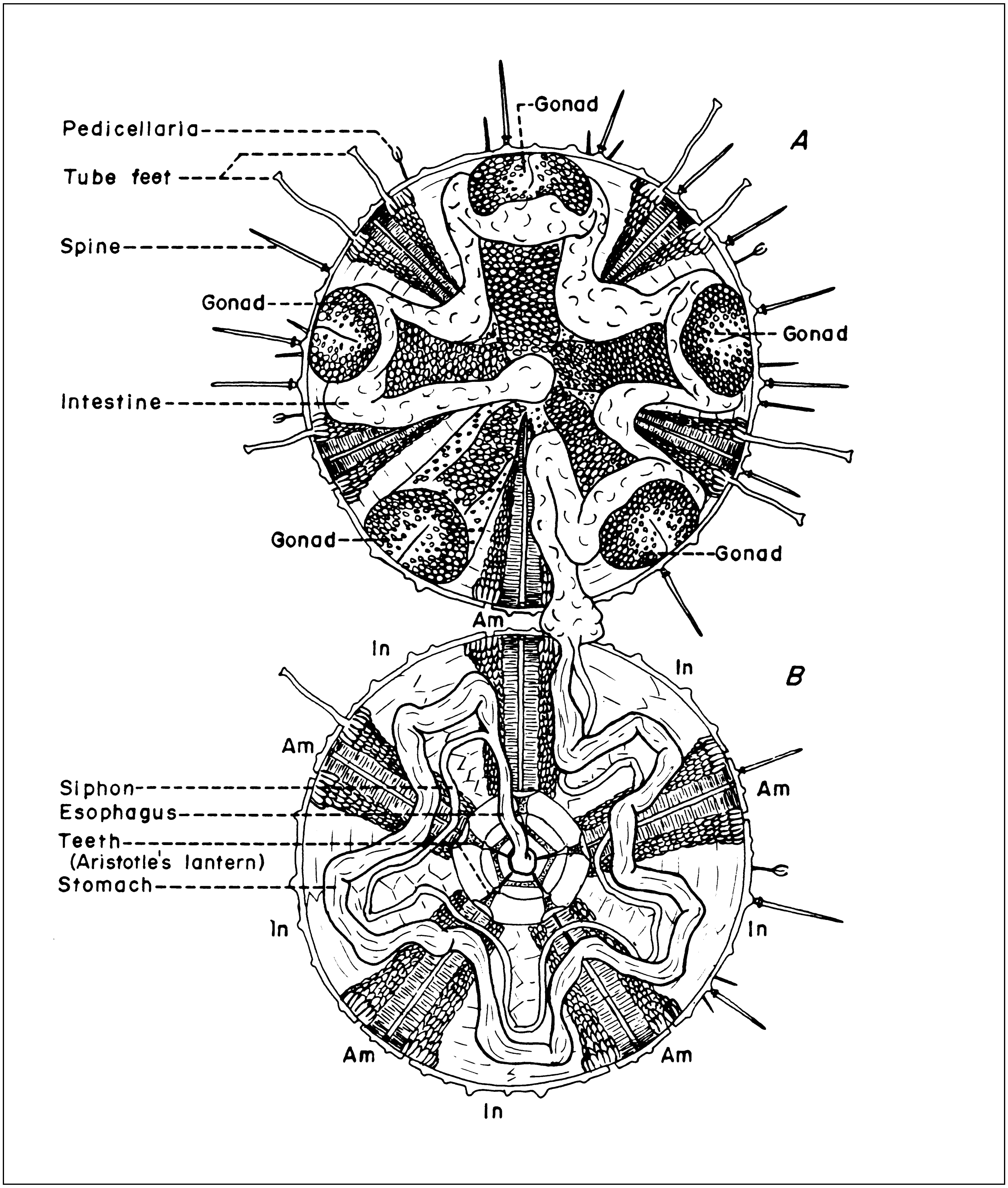

Figure 2. Internal anatomy of a sea urchin based on a specimen of *Strongylocentrotus purpuratus*. **A** shows the inside of the top (aboral) half of the sea urchin, and **B** shows the bottom (oral) half. The ambulacral and interambulacral areas are indicated by an **Am** or **In**, respectively. (Mottet, 1976)

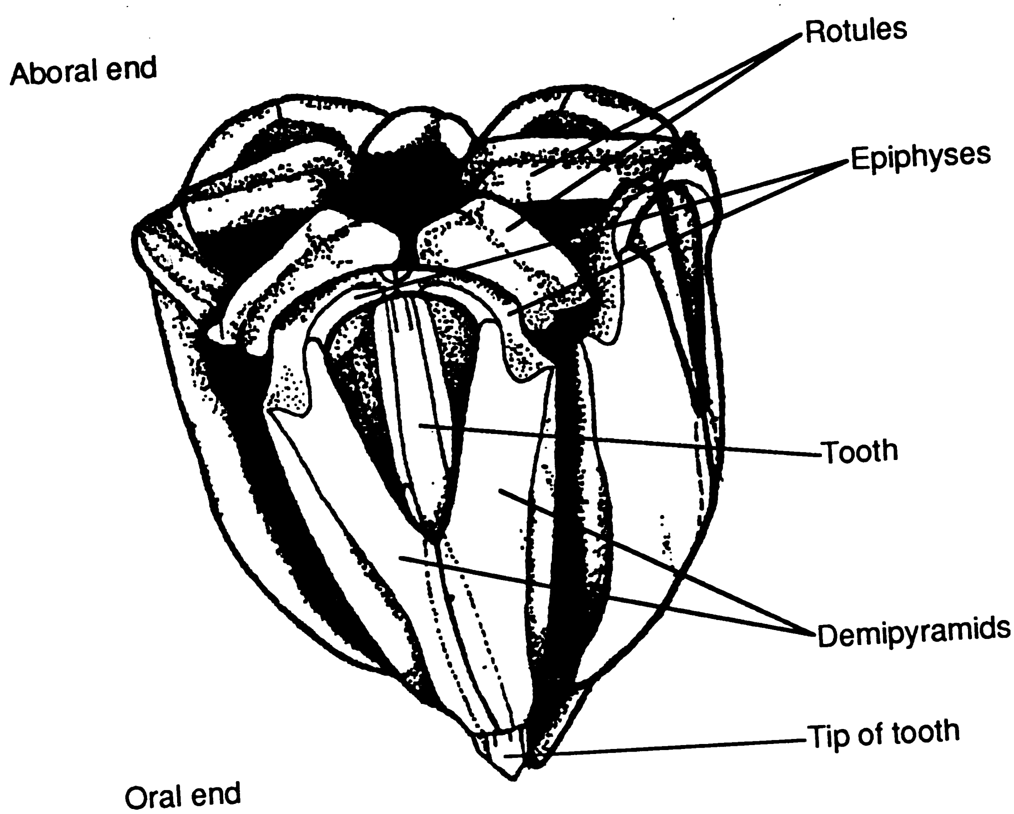

Figure 3: Red sea urchin Aristotle's lantern (Bureau, 1996).

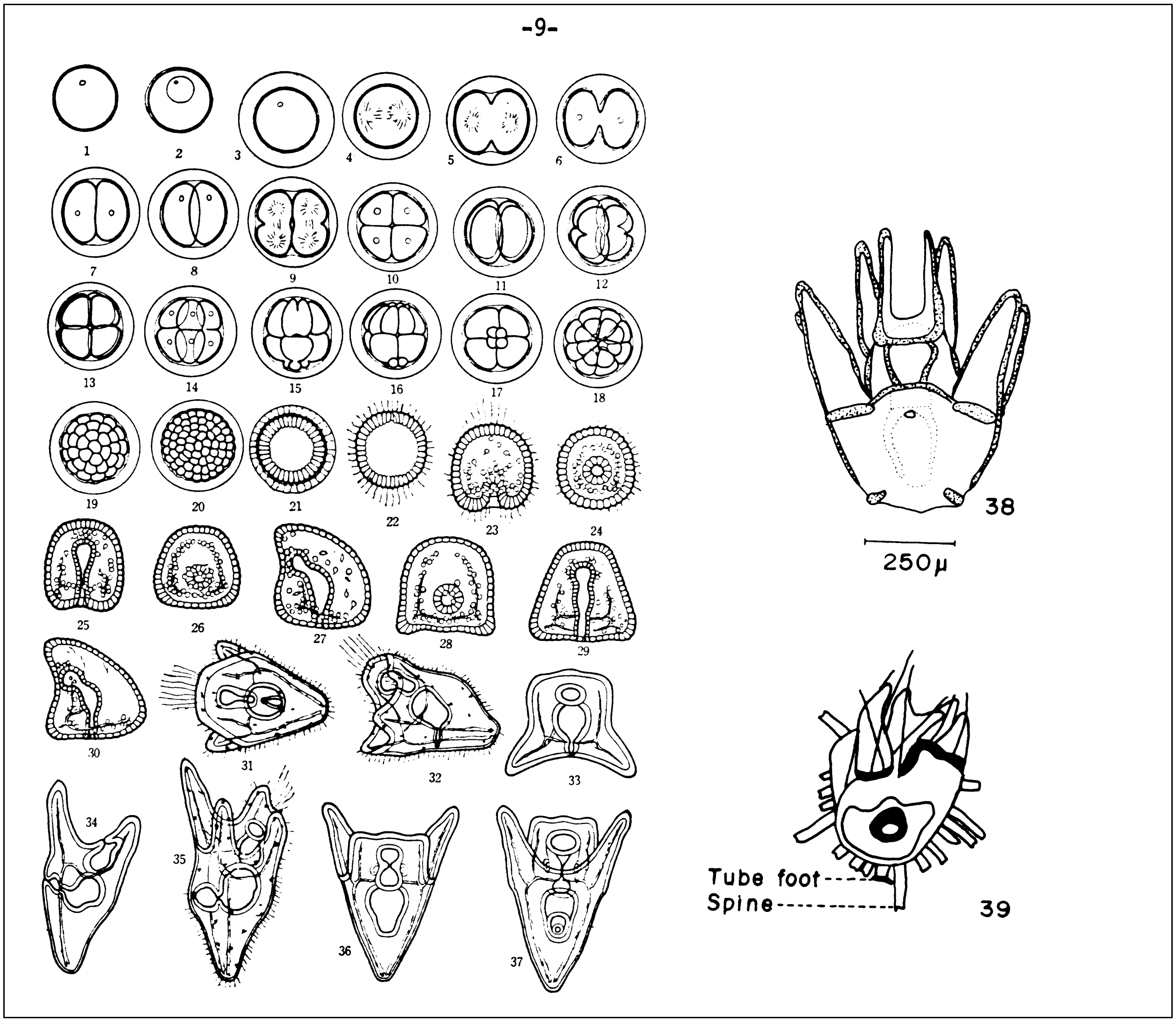

Figure 4: The larval development of sea urchins in the family Strongylocehtrotidae. Drawings 1-37 represent the larvae of Hemicentrotus pulcherrimus reared at temperatures of 10-15° C and are from Okada and Miyauchi (1954, in Mottet 1976). (1) Unfertilized egg, diameter 80-90µ; (2) mature egg; (3) fertilized egg; (4,5,6) first cleavage, 1.5-2.0 hours after fertilization; (7,8) views of two-cell stage, 2.0-2.5 hours; (9) second cell division; (10,11) views of four-cell stage, 3-4 hours; (12) third cell division; (13,14) views of eight-cell stage, 4-5 hours; (15) fourth cell division; (16,17) views of 16-cell stage, 5-6 hours; (18) 28-cell stage, 6-7 hours; (19) 64-cell stage, 9 hours; (20) early blastula, 160 cells, 14-16 hours; (21) blastula at 20 hours; (22) blastula with cilia at 23 hours; (23) gastrula at 32 hours; (24) at 42 hours; (25,26) views of late gastrula at 52 hours; (27,28) prism larva at 64 hours; (29,30) prism larva at 76 hours; (31,32) pluteus at 86 hours, length 200 µ; (33,34) at 100 hours, 270 µ; (35,36,37) pluteus at 120 hours, length 300 µ; (38) eight-arm pluteus of *Strongylocentrotus purpuratus* from Strathmann (1971, in Mottet 1976); (39) aboral view of *S. intermedius* larvae during metamorphosis, 926 µ, from Kawamura(1973, in Mottet, 1976).

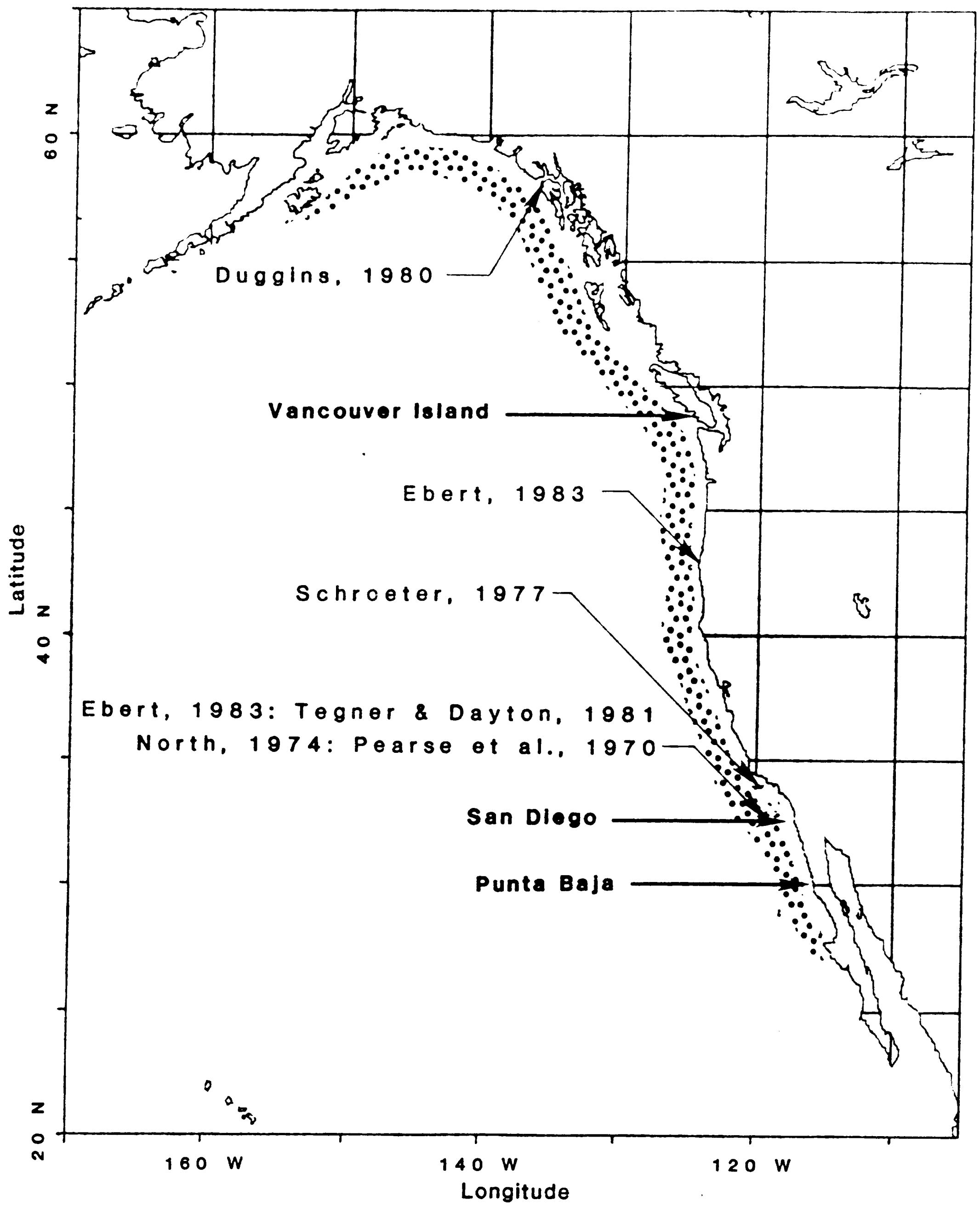

Figure 5: Map showing the distribution of *S. purpuratus* along the west coast of North America and sites of previous studies. (Russell, 1987)

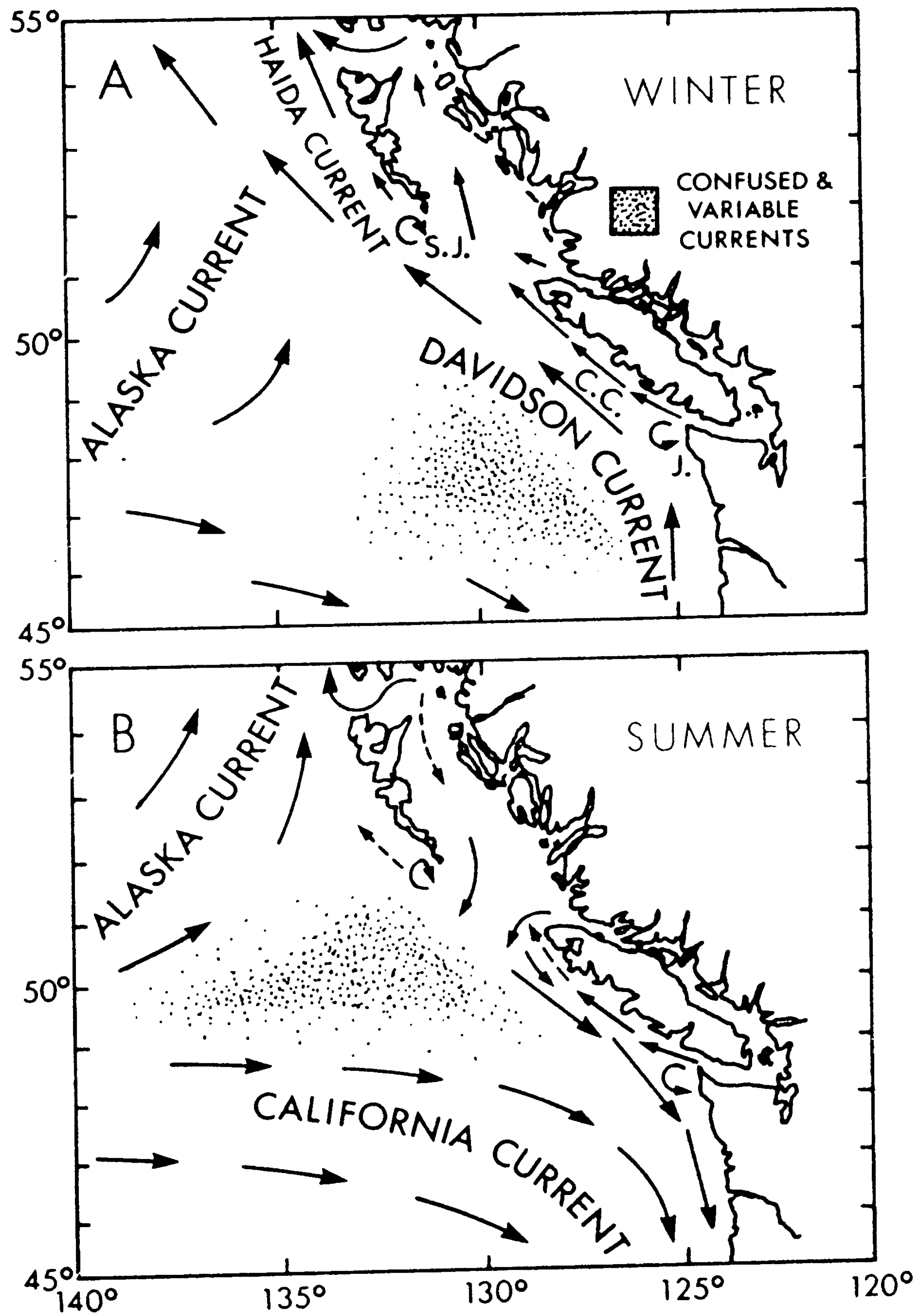

Figure 6: The prevailing Currents off the west Coast of Canada. The Subarctic Current splits into the pole-ward flowing Alaska current and the equatorial flowing California current (Thompson, 1981).

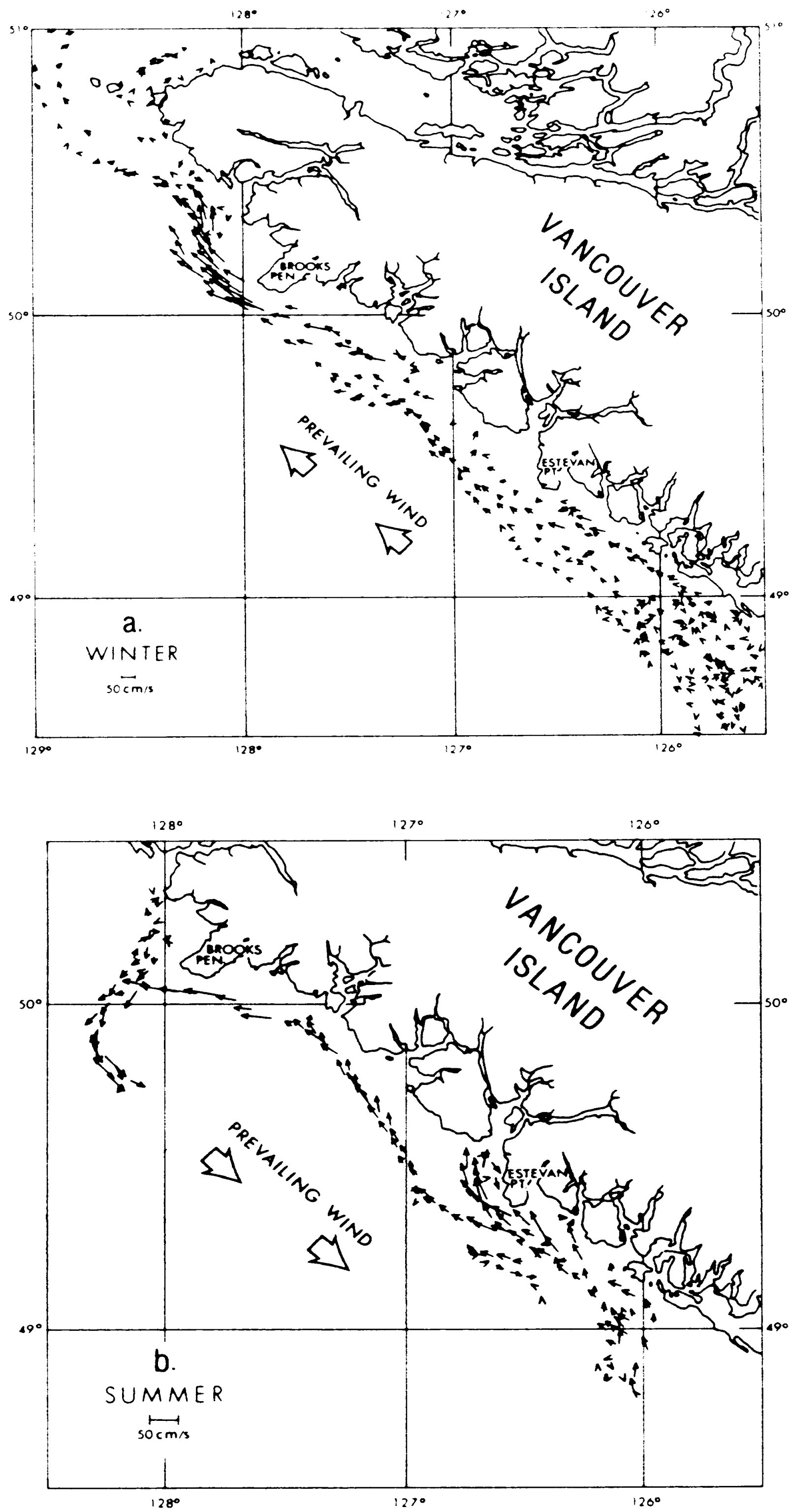

Figure 7: Vancouver Island Coastal Current. Spatially averaged (over 5 km intervals) buoy trajectory speeds from the 1984 Canadian search and rescue Project (CANSARP) for a) winter and b) summer. (Thompson et al., 1989)