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A Review of California Mussel (*Mytilus californianus*) Fisheries Biology and Fisheries Programs

D. Schmidt

North Island Biological Consultants Ltd.
5088A Beaver Harbour Road
Box 2437
Port Hardy, BC V0N 2P0

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1.0 Abstract

This paper is a literature review of all available and relevant information on past and present data concerning the California mussel (*Mytilus californianus*) for the purposes of establishing a fishery on *M. californianus*. A group located on North Vancouver Island, British Columbia (BC), the Vancouver Island Shellfish Cooperative (VISCO), has expressed an interest in starting a commercial harvest on California mussels for the purpose of creating jobs in the winter months (G. Caumanus, VISCO, pers. comm.). Market information indicates that there is a demand for new mussel fisheries as existing mussel fisheries cannot supply the increasing demand for mussels (Krause 1997).

In the development of new fisheries, Fisheries and Oceans (DFO) has developed a new protocol to prevent damaging the species in question. Perry (1996) set out this protocol in detail describing the required process. Three phases or main steps were identified in Perry (1996). This paper is the first phase (Phase 0) in the development of a new fishery. A review of all pertinent information including biological and ecological data as well as all related fishery records is the main purpose of the Phase 0 paper. Missing or lacking information is identified and recommendations for the collection of this data are given. Phase 1, the next step, involves the collection of this data and any other data that will help biologists and managers to decide whether the fishery could be feasible. The final phase, Phase 2, is an actual pilot harvesting project on a commercial scale to evaluate the effectiveness of the decisions and management plans made.

All pertinent information on California mussels has been collected, including relevant information on closely related species. Information that is lacking has been identified and will be filled in through the second phase (phase 1), which involves collection of data in the field through various biological assessments.

As no regulated California mussel fishery exists in Canada, the objectives of this paper are:

1. To complete a literature review of all available information on the biology, behavior and ecology of *M. californianus*;
2. To gather relevant data on closely related species to help put perspective on missing *M. californianus* information where possible;
3. To review information on past and present *M. californianus* fisheries outside of Canada;
4. To review information on unregulated fisheries inside of Canada;
5. To provide recommendations to managers to help decide whether an *M. californianus* fishery would be possible in British Columbia.

1.1 Résumé

Le présent document donne les résultats d'un examen des publications traitant de toute l'information disponible et pertinente, tant antérieure qu'actuelle, sur la moule de Californie (*Mytilus californianus*) dans l'optique de la mise sur pied d'une pêche de cette espèce. Un groupe du nord de l'île de Vancouver, en Colombie-Britannique (C.-B.), la «Vancouver Island Shellfish Cooperative» (VISCO), s'est dit intéressé à mettre sur pied une récolte commerciale de la moule de Californie dans le but de créer de l'emploi pendant l'hiver (G. Caumanus, VISCO, comm. pers.). Les données sur les marchés montrent l'existence d'une demande pour une nouvelle pêche de la moule car les pêches actuelles ne peuvent accommoder la demande à la hausse pour les moules (Krause, 1997).

Le ministère des Pêches et des Océans (MPO) a élaboré un nouveau protocole pour le développement de nouvelles pêches afin d'éviter les effets nuisibles pour les espèces visées. Perry (1996) a décrit le protocole de façon détaillée et a dégagé trois grandes étapes du processus. Le présent document constitue la première étape (étape 0) du développement d'une nouvelle pêche. Cette étape a pour principal objectif la réalisation d'un examen de toute l'information pertinente, notamment les données biologiques et écologiques et les résultats de pêches connexes. Les renseignements absents ou disparus sont précisés et des recommandations sont formulées pour leur obtention. L'étape 1, l'étape suivante, consiste en la collecte de ces données et de toutes autres données pouvant s'avérer utiles aux biologistes et aux gestionnaires pour déterminer la faisabilité de la pêche. La dernière étape, l'étape 2, est représentée par un projet de pêche pilote à l'échelle commerciale qui vise à évaluer l'efficacité des décisions et des plans de gestion adoptés.

Tous les renseignements pertinents sur la moule de Californie, et des espèces très apparentées, ont été obtenus. Les carences d'information ont été définies et seront comblées au cours de la deuxième étape (étape 1) qui comporte la collecte de données sur le terrain par le moyen de diverses évaluations biologiques.

Étant donné l'absence d'une pêche réglementée de la moule de Californie au Canada, le présent document a pour objectifs :

1. de compléter l'examen de toutes les publications disponibles sur la biologie, le comportement et l'écologie de *M. californianus*;
2. de récolter des données pertinentes sur des espèces très apparentées afin de mieux mettre en perspective les carences d'information *M. californianus*;
3. d'examiner les renseignements sur les pêches actuelles et antérieures de *M. californianus* réalisées à l'extérieur du Canada;
4. d'examiner les renseignements sur les pêches non réglementées faites au Canada; et
5. de formuler des recommandations aux gestionnaires dans l'optique d'une décision sur la faisabilité d'une pêche de *M. californianus* en Colombie-Britannique.

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2.0 Biology of the California mussel (*Mytilus californianus*)

The biology of the California mussel has not been well studied. Much of the information available is made in reference to the closely related blue mussel (*Mytilus edulis*), as it is much more prevalent worldwide.

2.1 Description and Taxonomy

California mussels[1] are classified as belonging to the Phylum Mollusca, Class Bivalvia, Subclass Pteriomorphia, Order Filibranchia, Suborder Mytilacea, and Family Mytilidae (White 1937; Yonge 1976; Seed and Suchanek 1992). The genus *Mytilus* is the most diverse of the family Mytilidae, of which California mussels are a part (Seed and Suchanek 1992). Closely related to *M. californianus* is the blue mussel[2] (*Mytilus edulis*). Recent studies have indicated that, rather than a single species, what is thought of as the blue mussel is actually three closely related species – *M. edulis, M. trossulus and M. galloprovincialis* (Seed and Suchanek 1992; Harbo 1997). It is thought the species referred to as *M. edulis* or the blue mussel on the Pacific Coast is in fact *M. trossulus* (Gosling 1992), with *M. edulis* suggested as being accidentally introduced in mussel farming operations.

M. californianus is a bivalve mollusk which has a generally triangular and inequilateral shell (White 1937; Gosling 1992). It can usually be distinguished from other species by its extremely thick and coarse shell with strong radial ribs, often worn bluish colored periostracum, blunt shell form and its large size in undisturbed beds (Gosling 1992; Harbo 1997) (Figure 1). The meat of *M. californianus* is a bright orange in color as compared to the brownish appearance of other related mussels (Harbo 1997). The presence of a byssal organ and byssal threads, common to the order, is present in *M. californianus,* which attaches the mussel to its substrate, although they are much stronger in *M. californianus* than the other *Mytilus* species. The presence of an anterior adductor muscle, a posterior adductor muscle along with a pitted resilial ridge and a denticulated hinge (hinge teeth), help to differentiate between the genera *Mytilus* and other related genera (White 1937; Gosling 1992)(Figure 2). California mussels are known to produce pearls, both loose and blister pearls, the latter of which appear as projections on the inner lining of the shell (White 1937; Quayle 1978).

2.2 Distribution

M. californianus is present throughout much of the west coast of North America (Figure 3) extending from the coasts of the Aleutian Islands in Alaska to Northern Mexico

[1] Numerous common names exist for the California mussel. Shaw et al. (1988) and Harbo (1997) list sea mussel, ribbed mussel, California sea mussel, and big mussel as alternately used names.
[2] Like the California mussel, the Blue mussel has many common names. Shaw et al. (1988) lists bay mussel, edible mussel, black mussel, and pile mussel as other common names.

(Socorro Island)(Suchanek 1981; Shaw et al. 1988; Dittman and Robles 1991; Gosling 1992; Harbo 1997). This distribution is limited primarily by freezing temperatures in the north to high water temperatures in the south (Seed 1976; Shaw et al. 1988; Gosling 1992).

Exposed rocky intertidal zones on the coast are the primary habitat of *M. californianus* (White 1937; Seed 1976; Yamada and Peters 1988; Gosling 1992; Harbo 1997). However, while dominant in most areas where it has gained a foothold, *M. californianus* will not readily colonize bare rock, but rather attaches itself to other mussels, like *M. edulis* or existing *M. californianus,* (Yamada and Peters 1988), forming thick beds of mussels. As they do not colonize bare rock, it has been estimated that it can take anywhere from 5 to 100 years for *M. californianus* to recolonize areas that have been denuded of *M. californianus* (Yamada and Dunham 1989). Very small gaps (< 100 cm^2), in contrast, are filled in very quickly due to the presence of adults on the gap edges "leaning" in to fill the gap (Seed and Suchanek 1992). In addition to attaching to other mussels, filamentous substrates are also utilized (Paine 1974; Chalfant et al. 1980), especially the filamentous red algae, *Endocladia muricata* (Robles and Robb 1993). Wave exposed coasts rather than sheltered bays are preferred by *M. californianus.* The most likely reason for this preference is its intolerance to low salinity and sedimentation (Harger 1968; Harger and Landenberger 1971; Yamada and Peters 1988).

The highest concentrations of *M. californianus* are found in the intertidal zone. Literature values for the vertical height are estimates at best, but one study suggests that 2.4 to 3.0 m above the lower low water mark is the upper limit of the mussels and this fluctuates greatly according to seasonal temperatures (Paine 1974). Lower limits of *M. californianus* in the intertidal zone are limited by the presence of predators, primarily the seastar *Pisaster* spp. (Seed and Suchanek 1992; Menge et al. 1994; Robles et al. 1995). Paine (1966, 1974, 1989) suggests a lower intertidal limit of 1.0 m above lower low water on the Oregon coast. Suchanek (1981) has identified limits of 1.3 m (lower limit) to 2.9 m (upper limit) above mean lower low water in Washington, USA.

Below the intertidal zone, *M. californianus* has been observed to depths of 30 m off the coast of Oregon (Seed and Suchanek 1992), and Harbo (1997) reports depths of up to 100 m. However, these subtidal beds are not continuous (Paine 1976, 1989), and occur in very isolated patches.

2.3 Life History

The following paragraph is adapted from Lutz and Kennish (1992),White (1937) and Bayne (1976). Sexes are separate in *M. californianus* with males producing spermatozoa (sperm) and females producing ovum (eggs). Eggs released from the female are generally ovoid in shape when unfertilized and become spherical only when fertilized – a good indication of a fertilized egg. If not fertilized within 3-4 hours, the egg does not progress further and dies. Once fertilized, the egg develops into the first free-swimming larval stage called the **trochophore** in 4-24 hours (Figure 4a). In 24-48 hours the trochophore develops into a **veliger** larvae (Figure 4b). The veliger secretes the first of two larval shells within an additional 10-12 hours. Further growth and development occur, changing the veliger into the **velichoncha** larvae, which secretes the second larval shell. At this time, the velichoncha grows relatively quickly, reaching 0.110 mm to 0.250 mm. When the velichoncha reaches the 0.220 mm to 0.260 mm range, the foot starts to develop and it is now called a **pediveliger** larvae. It should be noted that in addition to being mobile, the larvae from the veliger stage is able to feed on microplankton through a rudimentary gastrointestinal system. From the pediveliger larval stage, metamorphosis occurs. Adult structures such as gills, labial palps and the byssal organ develop and the adult shell is secreted. During this major change, the larvae loses the ability to feed until the adult organs develop; a period of 1-3 days. Once metamorphosis is complete, and the pediveliger has settled, the post-larval mussel is then called a **plantigrade.**

During larval development to the plantigrade, the larvae are suspended in the water column, making up a significant proportion of the plankton in the water. Settlement from this stage takes anywhere from 3-5 weeks (Seed 1969; Bayne 1976; Seed and Suchanek 1992) depending on water temperature and the presence of a place to settle. Approximate size of the plantigrades ranges from 1.0 mm to 10.0 mm, again largely dependent on the time spent in the water column with larger sizes corresponding to longer times in the water column (Petersen 1984a). At this point, the pediveligers secrete byssal threads and attach themselves to the substrate (Seed 1969; Bayne 1976; Petersen 1984a; Lutz and Kennish 1992). Unlike *M. edulis, M. californianus* does not have a recognized secondary settlement stage (Paine 1974; Petersen 1984a). As a result, if the larvae do not settle on suitable substrate, mortality at this point can be high.

Actual settlement of the pediveligers is highly variable over both space and time (Paine 1974; Connell 1985). While Yamada and Peters (1988) indicated *M. californianus* will not colonize bare rock, Petersen (1984a) found that the pediveligers prefer complex substrates, especially *Endocladia muricata.* Chalfant et al. (1980) indicated larval preferences for filamentous algae. As well, high concentrations of plantigrades can be found attached to the byssal threads of adult mussels (Bayne 1964; Dayton 1971; Petraitis 1978).

2.3.1 Reproduction

Age at maturity is not specified for *M. californianus. M. edulis* has been seen to sexually mature at age 1 (Seed 1976). The size at maturity is highly variable and depends primarily on local conditions such as water temperature and food availability (Seed 1976; Seed and Suchanek 1992). White (1937) reported confirmed full ova development in *M. edulis* at 1.3 inches (3.3 cm), while undocumented reports exist of smaller animals having full ova development. Coe and Fox (1942) estimated a 70 mm size at first spawning in southern California.

M. californianus spawns continually throughout the year, although for most of the year, the amount of gametes released are quite low with peaks appearing in spring and fall (Young 1946; Yamada and Dunham 1989; Seed and Suchanek 1992). Actual recruitment starts in the winter months and peaks in the summer in California (Paine 1974; Robles et al. 1995). It has also been observed that *M. californianus* exhibits a general yearly pattern of low recruitment punctuated by intervals of high recruitment (Dayton 1971; Paine 1974; Seed and Suchanek 1992; Robles et al. 1995).

The overall reproductive strategy of *M. californianus* is one of high fecundity (Bayne 1976). The numbers of eggs a female releases throughout the year is highly dependent on size, with larger females producing greater numbers of eggs. Seed (1976) and Widdows (1991) found a range of 5-12 million eggs per female per year. White (1937) reports that a 3.5 inch (8.9 cm) female produces an average of 25 million eggs per year. Seed and Suchanek (1992) report an *M. edulis* female which produced 40 million eggs in one spawning period. Actual egg size of *M. californianus* has not been reported in the literature, although the eggs from *M. edulis* are considered to be representative of the genus at 0.07 mm diameter (White 1937; Seed and Suchanek 1992).

Actual spawning takes place outside the body, with both the female and male excreting gametes into the water (Widdows 1991). Fertilization is thus by random chance in the water column. Probability of fertilization is further reduced due to the short (3-4 hour) lifespan of the gametes once released by the adult mussel (White 1937; Lutz and Kennish 1992).

At this time it is unknown what cues the onset of reproduction. Temperature, salinity, and food abundance have been suggested as possible exogenous cues (Seed 1976; Elvin and Gonor 1979; Seed and Suchanek 1992). Possible endogenous cues include nutrient reserves, hormone cycles and genotype. It has also been suggested that gametes and hormones from other mussels act as a cue, although this does not explain the continuous reproduction of *M. californianus* throughout the year (Elvin and Gonor 1979). In the laboratory, *M. californianus* has been induced to spawn through a number of different methods. Shaw et al. (1988) lists changing water temperature, adding single-cell algae to the tanks, ultraviolet light treated water, mussel sperm, hydrogen peroxide, rough handling and introduction of kraft mill effluent as successfully initiating spawning.

2.3.2 Age and Growth

Once attached to a suitable site, the post-larval plantigrade establishes itself and grows to adult sizes. Growth at this point averages around 0.4 to 2.3 mm/month for intertidal juvenile *M. californianus* on the coast of Oregon (Yamada and Dunham 1989). Growth in *M. californianus* displays a trend to a decreasing growth rate in older animals (Seed 1976; Seed and Suchanek 1992). Coe and Fox (1942) found the growth of subtidally suspended *M. californianus* in southern California to range from 3.75 - 5.0 mm/month for animals <30 mm, 2.67 – 3.83 mm/month for 40 – 70 mm animals, and 1.17 – 2.00 mm/month for animals >70 mm. Subtidal animals in Oregon grew at a slightly faster rate, 0.6 – 6.0 mm/month while intertidal adult mussels averaged 0.4 to 1.4 mm/month (Yamada and Peters 1988; Yamada and Dunham 1989). While subtidal animals grow faster than intertidal animals (due to subtidal animals being submerged all the time increasing food availability), a trend of decreasing growth rates as sites progress northwards can be seen from the above data indicating even slower growth rates for mussels in BC. Growth rates are highly variable due to water temperature, salinity, suitable substrate, food availability, elevation in the intertidal zone and relative crowding of the mussel bed (Yamada and Peters 1988; Yamada and Dunham 1989).

The growth rate of all species of mussels decreases or stops in the winter months as a result of the cooler water temperatures (Seed 1976; Yamada and Dunham 1989; Seed and Suchanek 1992). Growth was found to be the greatest in the range of temperatures from 15 to 19°C, slowing or stopping at temperatures outside this range (Coe and Fox 1942; Seed, 1976; Seed and Suchanek 1992). The higher the position in the intertidal zone, the slower the growth rate. This is due to the mussel being exposed to the air for longer periods of time, reducing time spent feeding and respiring (Dittman and Robles 1991).

Maximum ages for *M. californianus* are not known. Seed and Suchanek (1992) suggest that 50 – 100 years is highly possible in undisturbed patches of *M. californianus* while *M. edulis* has a reported maximum age range of 18 - 24 years. Age can be determined by counting annual rings on the outside of the shell, although this is unreliable due to additional rings being produced by differing environmental conditions (Seed and Suchanek 1992). Older rings can be worn away through abrasion. A cross section through the shell near the umbo region exposes faint lines where the nacreous layer is laid down annually. Microscopic examination can give a relatively accurate account of the age (Lutz 1976; Seed and Suchanek 1992).

Maximum lengths are relatively large in *M. californianus.* Suchanek (1981) found that the largest intertidal *M. californianus* were 200 mm while in the subtidal zone, mussels were found up to 250 mm (Paine 1976). This compares to 140 mm for *M. edulis* in the lower intertidal zones (Suchanek 1981).

2.3.3 Mortality

Mortality in mussels is very high, one of the reasons for the massive amounts of sexual products released during reproduction. Seed (1976) calculated mortality rates for *M. edulis* based on shell length (Table 1). However, conflicting results were obtained by Dare (1976) who found mortality rates of 74% and 98% for 25 mm and 50 mm shell lengths respectively, in the Morcambe Sea.

Larvae experience the highest rate of mortality. Bayne (1976) reports values as high as 99% for *Mytilus* spp. while in the planktonic stage (before settlement). J∅rgensen (1981) followed a cohort of *M. edulis* while in the planktonic stage and found a daily mortality to be 13%. Thus, the longer the mussels spend in the planktonic stage, the higher the mortality and lower the recruitment. While this seems excessive, given the large numbers of eggs released into the environment, 7 million plus per female, 1% survival would represent 70,000 plantigrades surviving to settle on the substrate. Ayers (1956) estimated 40 plantigrades/breeding pair sufficient to maintain a stable population of *Mya arenaria.* While this illustrates a point for one population, given that biological and ecological pressures are different for *M. californianus*, the number of plantigrades produced by the collection of breeding pairs in a given population should be enough to maintain a stable population barring any large scale disturbances.

Causes of *M. californianus* mortality are exposure to temperature extremes, desiccation at higher intertidal positions, low salinity, sedimentation, excessive wave action with associated log battering, predation, and disease and parasites (Seed 1976; Seed and Suchanek 1992). Old age in adults contributes somewhat to overall mortality, and although actual values are not reported, they are expected to be small due to the low probability of mussels reaching maximum ages. One source of mortality more prevalent in larvae is mortality due to being swept out to sea before settlement. Adults experience this to some degree (removal off substrate due to some disturbance), although due to their larger size, usually end up in a different location in the intertidal zone in the same bed (Paine 1976; Robles et al. 1995).

2.4 Parasites and Diseases

Bower (1992) and Bower and Figueras (1989) reviewed literature on parasites and diseases of mussels. Mussels of the genus *Mytilus* were found to contain numerous and various types of parasites including organisms from bacteria, viruses, protozoa, mesozoa, porifera, trematoda, cnidaria, fungi, protophyta, mesozoa, turbellaria, cestoda, nematoda, annelida, copepoda, decapoda and pantopoda. Mortalities as a result of these invasions are usually very low and site specific. However, Bower (1992) suggests that caution be used in transport and handling of mussels to prevent possible spread of potentially harmful parasites to different mussel populations. One set of diseases of concern are grouped together and loosely termed Haemocytic Neoplasia, or proliferate growth of abnormal haemocytes (Bower 1992). Found in the Puget Sound and some areas of Southern BC, occurrences can be found as high as 40%. A lethal disease, it produces mortality rates that exceed 75% in *Mytilus edulis* animals with shells over 4 cm in length. The causative agent has not been identified and it has been suggested it may be a different subspecies of Haemocytic Neoplasia which completes its life cycle in this manner. As yet, no occurrences have been reported in *M. californianus.*

One macroparasite which is prevalent in the mantle cavity of all *Mytilus* species is the pea crab (*Pimmixia* spp. *and Fabia* spp.) (Seed 1976; Bower 1992). While the pea crab does not harm the host, there is evidence that it reduces the growth rate of the mussel (Seed 1976). Some damage is done to the gill filaments, although it is minor and apparently does not affect the host to any great degree. The primary problem with pea crabs is that they tend to reduce the marketability of animals containing this parasite (Bower 1992).

Of particular concern is the ability of mussels to pass on harmful bacteria and diseases when consumed by humans. As these organisms are filter feeders, potentially any waterborne pathogen can be transmitted through poorly cooked shellfish (Shumway 1992). Diseases of note include hepatitis A, polio, typhoid, dysentary, cholera and fecal bacteria (Shumway 1992). While most are not common and only reported off the coast of Europe (namely typhoid, dysentary, polio, and cholera), the risk of these pathogens being present increases where human contaminants containing these diseases enter the water. Mussels, in addition to being efficient at picking up these organisms, are able to quickly get rid of bacterial diseases (Shumway 1992). Success in elimination of viruses is not well known, although evacuation times are thought to take a lot longer (Shumway 1992). Depuration facilities utilizing ozone, chlorine, or UV radiation treated water successfully remove bacteria from the mussels in a relatively short period.

While not toxic to mussels, the “red tide” is of extreme importance for human consumption of contaminated mussels. The red tide involves blooms of toxic algae whereby mussels filter out the algae and associated toxins. Due to the extremely high numbers of algae in the water the mussels build up large quantities of the toxins to a point where they cause serious problems in humans ranging from gastroenteritis like symptoms to fatalities (Shumway 1992). Three types of poisoning are known: paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and diarrhetic shellfish poisoning (DSP). ASP and PSP can prove fatal whereas DSP can be and often is confused with gastroenteritis (Shumway 1992). Toxins accumulated in the mussel can be purged by the mussel over time, and depending on the toxin, requires from 1 week to 3 months in relatively clean water (Shumway 1992). Depuration facilities do work, but require the same amount of time to cleanse the mussels as would take naturally. It should be noted that cooking of the mussel **does not** break down the toxin to any great degree and great care and diligence should be taken when consuming mussels.

2.5 Trophic Relations

M. californianus is generally a sessile animal. With the exception of the larval stage and the occasional random detachment from its substrate, *M. californianus* spends its life in one spot, unlike *M. edulis* which exhibits a crawling type of behavior (movement through attachment of new byssal threads and discarding of old threads) (Seed and Suchanek 1992).

The primary diet of California mussels consists of organic debris, dinoflagellates, diatoms, silicoflagellates and bacteria (Coe and Fox 1942). Other foods include algae and algal spores, flagellates, ciliates, other protozoa, spermatozoa and ova (Shaw et al. 1988). Suspended particles and plankton are trapped by the gill cilia and directed towards the mouth and stomach (Bayne et al. 1976; Shaw et al. 1988). Large amounts of water are filtered in the process ranging from 50 - 3000 mL/min (Bayne et al. 1976). Rates are highly temperature dependent with lower filtration rates occurring at lower water temperatures. Note that these rates were only found for *M. edulis*.

M. californianus is considered a food species and has numerous species which prey upon it (Table 2). While the genus *Mytilus* is a preferred food source of many predators, *M. edulis, M. trossulus, and M. galoprovincialis* are selected for before *M. californianus* is (Robles et al. 1995). The seastar *Pisaster ochraceus* is considered one of the main factors in establishing the lower intertidal limit of *M. californianus* in most areas (Dayton 1971; Paine 1974; Seed 1976; Connell 1985; Seed and Suchanek 1992; Lohse 1993a;

Robles et al. 1995; Berlow 1997). As a result, positive correlations have been observed between *M. californianus* abundance and *Pisaster* abundance (Seed 1976; Seed and Suchanek 1992; Robles et al. 1995). That is, when *M. californianus* recruitment and abundance is high, more *Pisaster* move into that area increasing overall *Pisaster* abundance.

Two mechanisms exist whereby *M. californianus* can limit predation by *Pisaster*: its location on wave-exposed sites, and its large thick shell in older adults. If the mussel can survive long enough to reach a relatively large size, *Pisaster* is unable to prey upon the mussel. As well the location on exposed sites prevents *Pisaster* from getting to the mussels (Paine 1974; Seed 1976; Suchanek 1981; Seed and Suchanek 1992; Robles et al. 1995). Other predators are not limited by these factors and do exert a low level of pressure on *M. californianus* (Paine 1974; Seed 1976; Seed and Suchanek 1992). The presence of the gooseneck barnacle (*Pollicipes polymerus*) in *M. californianus* and *M. edulis* beds helps to reduce predation pressure from gulls and oystercatchers as the gooseneck is preferred over *Mytilus* (Wootton 1992,1993).

2.5.1 Competition

M. californianus is a very dominant competitor and will out compete all plant and animal species in an intertidal bed (Paine 1974; Petersen 1984b; Robles and Robb 1993; Robles et al. 1995). Its prime competitors, *M. edulis, M. trossulus, M. galloprovincialis,* and *Pollicipes polymerus*, will eventually disappear from a site given time. Due to the fact that *M. californianus* actually prefers to settle on other mussels and barnacles gives it a competitive advantage, eventually growing large enough to smother the mussels or animals below. Competition with the gooseneck barnacle is slower as evidenced by the removal of the barnacle by predators (ie gulls) (Wootton 1992). It was found that species diversity on a site with both *M. californianus* and the gooseneck barnacle remained relatively the same until the barnacle was removed via predation, at which point, *M. californianus* greatly increased the percent cover of the site. Paine (1974) studied one particular bed of gooseneck barnacles and California mussels. At a particular spot in this bed, only gooseneck barnacles were present. After six years, no gooseneck barnacles could be found, but were replaced by *M. californianus.* Meese (1993) had conflicting results. After three years, no evidence was found of the gooseneck barnacle being replaced by *M. californianus*. These results should be used with caution as the study period was half of that of Paine's 1974 study.

While competitive abilities for the California mussel are high on relative horizontal surfaces, they cannot compete on near-vertical to vertical faces (Paine 1974). It is thought that this is due to the large size of the California mussel – once they reach a certain size, their weight combined with wave pressures is too much for their byssal threads to handle and consequently can not survive on these faces (Paine 1974).

Competition between algae and mussels is generally not well studied. Dittman and Robles (1991) studied the interactions of California mussels and various species of red algae (*Corallina officinalis, Gigartina canaliculata, and Gelidium coulteri*). It was found that the California mussel was only able to outcompete the algae in wave exposed areas, the mussel's preferred habitat. All other habitats had varying degrees of mussel concentrations from zero to approximately equal proportions of algae and mussels. This indicates that while the California mussel is a dominant competitor, it is strongest in its preferred wave exposed habitat. Blanchette (1996) studied the sea palm (*Postelsia palmaeformis*) and found that during the fall and winter months, survival of young *Postelsia* was enhanced beneath *M. californianus* beds. In addition, once a large scale disturbance event removed some of the mussels, *Postelsia* was released and grew to adult sizes. Large blooms of algal epiphytes growing on *M. californianus* have been found to slightly reduce growth rates as well as lower reproduction rates of the mussels (Dittman and Robles 1991).

Takeover of a site not colonized by *M. californianus* can occur in two different yet similar ways. Influx of larvae to the site from other areas and subsequent settlement and survival of the larvae, and migration of adult *M. californianus* and subsequent establishment. The second situation is less likely as it involves the removal of an adult from one site and movement through wave and current action to some distant site. This is less likely to occur due to the size and weight of the adult mussel which would tend to move it to subtidal areas (Suchanek 1981).

2.6 Population Structure and Dynamics

M. californianus populations are known to undergo considerable variation in abundance from year-to-year (Dayton 1971; Paine 1974; Seed 1976; Connell 1985; Seed and Suchanek 1992; Lohse 1993b; Robles et al. 1995; Berlow 1997). Many factors are involved such as predation, water temperatures, and environmental stresses. Generally, as you progress upwards from the low intertidal to the high intertidal, large animals are prevalent in the low intertidal (Pers. observ.; Paine 1974; Suchanek 1992). The mid intertidal area consists of layers of mussels with smaller mussels scattered throughout a base of large mussels. The high intertidal area consists mainly of small to mid-size mussels generally in a single layer (Paine 1974, pers. observ.).

Sex ratios are fairly constant at all times within a population at 1:1 (Shaw et al. 1988; Seed and Suchanek 1992). It is not known whether differential mortality occurs between the sexes, although the sex ratio indicates in part, similar mortality rates. No evidence of sex change with age has been found (Shaw et al. 1988).

Literature information on the sizes of beds is limited. Through personal observations, beds on the BC coast have been found to be extremely variable ranging from 26-1800 m^2 with both smaller and larger beds identified in the field (not yet measured). No mode for the size of beds can be seen from the preliminary data, although most beds surveyed are under 1000 m^2. Beds are not spatially contiguous over the entire area. Small and large gaps are present throughout. Density along contour intervals is also highly variable ranging from single layers to multi-layers within a bed.

2.7 Ecological Relationships

California mussel beds are complex structures being composed of (1) a physical matrix of interconnected living and dead mussel shells that may occur as a single layer or multiple layers (up to five or six mussel layers deep); (2) a layer of accumulated sediments composed of organic and shell debris; and (3) a diverse assemblage of plants and animals associated with the mussels (Suchanek 1992). *M. californianus* beds represent one of the most diverse temperate communities described to date with more than 300 taxa identified living amongst the mussels (Yamada and Peters 1988; Paine 1989; Suchanek 1980, 1992). As mussel beds age, the structural complexity of the bed increases, which leads to a more diverse community associated with the mussels (Suchanek 1992). This can be seen within a single mussel bed itself. Community diversity within a 0.10 m^2 area ranges from 25 species in the high intertidal area to approximately 135 species in the low intertidal zone (Suchanek 1992). This corresponds to the changing complexity of the mussel bed which exists only as a single layer in the high intertidal zone (Paine 1974) to as many as 6 in the lower intertidal zone (Paine 1974; Suchanek 1992). These layers can form mats of California mussels up to 25 cm thick (Dayton 1971).

Once established at a site, *M. californianus* becomes the dominant species, only losing its competitive advantage after a large-scale removal of mussels (Paine 1974). Disturbances damage not only the *M. californianus* community, but the associated community as well, whether by natural causes such as excessive wave action, log battering and predators, or human related impacts (Suchanek 1992). Gaps which were created in the mussel population by such disturbances showed an 87% decrease in community diversity (Suchanek 1992). Small gaps created in the lower intertidal zone were repopulated quickly (weeks to months) while gaps in the high intertidal zone took considerably longer to recover, if ever (Suchanek 1992). Even small gaps created by log battering, wave action or predator action can be considerably enlarged due to wave action, further increasing the recovery time (Dayton 1971). Dayton (1971) studied 3 sites on the Washington coast and found that small gaps from 0.03 m^2 – 0.09 m^2 increased in size by 24 – 4,884%. The fact that many of the mussels are attached to other mussels rather than the substrate further increases the instability in a bed (Dayton 1971).

Through personal observations, log-battering plays a very important role in some areas. Some beaches on the northwest side of Hurst Island, BC, have been almost completely denuded of California mussels. Only small, isolated patches in sheltered crevices remain. Physical characteristics of the beaches is very similar to those nearby with the exception of a large number of logs being present on the high water mark of the Hurst Island beaches. It is thought that the excessive battering by the logs has made most of these beaches unsuitable for mussels.

3.0 Review of the *M. californianus* Fishery

Very little information is available for *M. californianus* fisheries in any of the literature. Since *M. californianus* is confined to the west coast of North America, only a limited number of countries can participate in a fishery. Canada, while it has numerous areas for *M. edulis* fisheries and culture, both on the east and west coasts, does not at this time participate in any regulated *M. californianus* fisheries. While information on *M. edulis* fisheries is available, due to the widely different habitat requirements of *M. californianus*, it is felt that information about the *M. edulis* fishery would not apply to a *M. californianus* fishery. *M. edulis* is primarily a pioneer species and readily colonizes bare rock, whereas *M. californianus* is a secondary species and only colonizes where mussels or other complex substrate structure exists.

Oregon, USA has the only known regulated fishery for *M. californianus* at the present time. California had a fishery in the past, but was shut down due to health concerns. BC participates in a very small unregulated fishery to obtain samples for the PSP monitoring program. The following is a brief description of these fisheries.

3.1 Oregon, USA Fishery

Oregon has a small wild stock mussel fishery involving both blue mussels (the primary species) and *M. californianus*. A minimal *M. californianus* harvest started in 1979 and increased gradually to 1984 (Yamada and Peters 1988). An existing blue mussel fishery continued through this period. It is interesting to note, no distinction between the two species is made in any of the Oregon Department of Fish and Wildlife (ODFW) reports or statistics (ODFW annual reports 1988 – 1997; ODFW catch statistics 1997). Harvest levels for available data are given in Table 3.

It is unknown what the individual species weights are as they have been combined and reported as one. No explanation was available for the large decrease in catch numbers for 1997. However, Yamada and Peters (1988) suggest that the mussels cannot reproduce fast enough to keep up with existing harvest levels.

An event worth mentioning involves a harvest area in Yachats State Park on the Oregon State coast. In 1979, a 20 m stretch of shoreline was denuded of *M. californianus* by harvesters using rakes. At the time of the report, Yamada and Peters (1988) reported that the damage is still very evident, as the mussels have not recolonized the area. As a result, new regulations were imposed which made it mandatory to leave at least one layer of mussels behind and all harvesting was to be done by hand-picking and not through the use of rakes or other implements.

3.2 California, USA Fishery

California, at the present time, does not have a commercial fishery for California mussels. However, a relatively large fishery did exist for a number of years, recorded data starting in 1916 (Shaw et al. 1988). Like the Oregon fishery, both California and blue mussels were harvested and landing data was not separated into species. In 1927, the California State Board of Health closed the majority of the beaches due to “mussel poisoning”, later found to be paralytic shellfish poisoning. This reduced the landings to a negligible amount for a number of years (Table 4). A bait fishery did exist for most of the years the harvest was allowed, with a peak in 1977. As well, a small sport fishery exists with a personal limit of 25 lbs/day, although catch statistics for the personal harvest are not known.

3.3 British Columbia, Canada Fishery

At the present time, BC does not participate in a regulated fishery. However, a small-unregulated fishery exists on the BC coast, its primary function to provide animals for use in the PSP monitoring program. The Canadian Shellfish Sanitation Program (CSSP) was developed over the years to monitor PSP and related toxin levels in shellfish harvested in Canadian waters (CSSP Web Page 1999). *M. californianus* is used as an indicator organism due to its efficient filtering capacity (K. Schallie, CSSP, pers. comm.). Toxins appear in the mussels very quickly enabling the CSSP to initiate closures before toxin levels become a health hazard.

M. californianus adults are harvested from exposed beaches on the West Coast and transferred to cages located in various spots where shellfish harvesting occurs. While the total amount harvested for the West Coast is not known, K. Schallie (Pers. comm.) has estimated a yearly harvest from a beach outside of Sooke, BC, to range from 1-3 tonnes per year. Mussels are harvested from the same beach each year and harvesters report no noticeable effects of the harvest.

The mussels harvested from the beach in Sooke represent only a very small part of the mussels collected for sampling along the BC coast. Numerous sampling stations are situated throughout the BC coast, each requiring their own samples. At this juncture, it would be almost impossible to estimate the amount of mussels harvested each year. However, based on the numbers harvested from the Sooke beach, the total amount harvested in BC, while not a significant amount, should not be overlooked.

In addition to PSP harvest, a small personal harvest exists. A quota of 25 mussels/day with a possession limit of 50 mussels is allowed per person (DFO 1998). No records are kept of this harvest, but amounts are expected to be insignificant, due to the relative isolation of the mussel beds.

4.0 Discussion

Very little background information can be found on *M. californianus*, and the information that is available, is lacking in specifics. Background information on related species (ie *Mytilus edulis*) may not be suitable for management and assessment of the target species, as *M. californianus* has enough biological characteristics that are different to make management a separate entity from that of *M. edulis*. Information presented on *M. edulis* should be used with caution. As such, any form of harvest, whether for research or commercial uses should be done with extreme care to prevent unforeseeable consequences in the future.

4.1 Information Requirements for Assessment and Management

This review revealed a very large shortcoming in available information in almost all aspects of the mussel *M. californianus*. Most available data is for areas south of BC in Oregon and California, USA. Given the lower water temperatures on the BC coast, physiological parameters of *M. californianus* would be different in these waters. Specific biological data from BC is lacking in most areas and needs to be determined before any management strategy can be set up.

4.1.1 Biological Information

Biological information that is required for management of *M. californianus* stocks in BC involves almost every aspect. Location of beds, relative size, density, and general length and weight data should be collected to find out how large an *M. californianus* population actually exists. Length and weight distributions of the mussels in each bed will be crucial in formulating decisions early in the process as the majority of the biomass in a bed is due to larger sized mussels. This may tend to indicate a larger harvestable biomass than actually exists. If very few market-sized mussels exist within a natural population, is it reasonable to proceed any further? While it may seem premature to discuss harvesting or possible harvesting, the fact remains that this project was initiated with the hopes of establishing a future harvest. While gathering information, this fact should be considered, not to structure the scientific surveys, but to provide for reality checks as to whether or not the surveys should continue.

While the above constitutes the requirements for initial surveys, all other aspects of *M. californianus* biology should be examined. Condition factors should be studied rather early in the surveys. This involves sacrificing a number of mussels and following methods recommended by Davenport and Chen (1987). Again, considering the end goals, poor condition factors may make California mussels undesirable to markets and the survey need not continue any further. Additional information that should be gathered sooner rather than later in the survey includes age structure, growth rates, recruitment and time of peak spawning periods. Effects of disturbance and related recovery times, temperature regimes, predator pressures, and biodiversity of the beds are other factors to be studied. Any other biological factor not mentioned here should be looked at as well given the lack of concrete data for BC.

4.1.2 Harvest Methods

While seemingly premature, a discussion of harvest methods has a very large impact on biological surveys of California mussels and is warranted. From all indications, improper harvest methods can seriously damage a bed. Even small gaps (>100 cm^2) take a long time to recover, from months to decades. A substantial decrease in species diversity, averaging anywhere from 50 - 87% (Suchanek 1992) occurs at the same time. As this is a fragile ecosystem, harvest methods need to be examined to determine, if possible, the least harmful method. Given the wide range of available methods, from "clearcutting" to selective harvesting, each should be examined to determine its effect on the population. If nothing else, it will provide data on the effects of disturbance in the mussel beds. No formal harvest should be done before these methods can be tested.

One of the possible methods to consider is a selective harvest of market sized individuals and a portion of the larger mussels. This has the effect of reducing crowding allowing the remaining mussels to grow faster (See section 2.3.2 Age and Growth). While on paper, this seems to be the best method, definite field-testing is required.

4.2 Assessment and Management of a *M. californianus* Fishery.

While it is very premature to discuss management scenarios, the methods required for the assessment and management of the mussel fishery may in themselves preclude a commercial harvest. To protect the fragile nature of the beds, strict monitoring protocol would be needed to ensure conformance. The following discusses possible protocol and methods that would be required in the management of an *M. californianus* fishery.

1) <u>Size Restrictions</u>. Minimum size limits are effective in management as animals too small for harvest can be successfully released back into the population. As well, they allow small animals to reach maturity and reproduce, the number of spawning periods variable according to the minimum size. Oregon State imposes a minimum of 2 inches (5 cm) shell length (J. Mcrae, ODFW, pers. comm.). Given average growth rates, this allows the mussel to reproduce at least once, possibly twice before harvest. A maximum size limit would be essential as the larger *M. californianus* provide habitat and a reliable source of gametes for future generations. Larger *M. californianus* are considerably more resistant to predation and will provide the basis for keeping up recruitment rates.

2) <u>Equipment Restrictions</u>. A restriction in the use of equipment is essential. As *M. californianus* does not colonize bare rock, use of any implement causing large scale removal should not be allowed. Hand picking, and even use of knives to cut byssal threads of individual mussels would be the preferred method of harvest. Hand

picking alone can pull the byssal threads out of the byssal organ damaging the mussel or even killing it. It cannot then be put back into the population if too small, and causes problems in maintaining quality in transportation.

3) Seasonal Closures. The collection of data on the local stocks can be used to set up seasonal closures to protect the animal during critical life stages. This can be periods of peak spawning or during periods when the mussel may have a lower condition index (ie late winter). In addition, with the threat of “red tide” summer closures will be necessary to prevent toxic poisoning in consumers.

4) Area Closures. Areas where sufficient data has not been collected should remain closed until such time as data can be gathered. Marginal habitat areas or areas of low production should be closed to prevent damaging the population. In these areas, harvest would not be feasible due to slow re-population. Some higher production areas should be set aside as well to act as refuges in case a large-scale die-off occurs. Recovery in these areas would be relatively fast and would help re-establish other populations through migration of larvae. Marine Protected Areas (MPA), Provincial parks, and National parks have been established or will be in the near future in the areas of question. These should be used as refuges as much as possible.

5) Observers. While costly, observers should be a necessary component of the harvesting of mussels. Strict monitoring of the mussel beds should be followed to prevent any mistakes from occurring. One mistake like that which occurred in Oregon (Section 3.1), can seriously damage the mussel population and associated community.

Area closures for high water contamination are needed. Mussels are susceptible to pollution and tend to build up concentrations of harmful materials in polluted areas. While depuration of the mussels is possible, guarantees that the mussel has been entirely cleaned are not 100%. Closures would have to reflect a balance between costs associated with depuration and public safety.

5.0 Conclusions

Information on all aspects of *M. californianus* needs to be collected. While it appears that sufficient biological data exists, the majority of it is for populations outside of BC. As *M. californianus* has only been a commercial species for a short period of time in the United States, it appears that collection of biological information has not been a high priority of fisheries managers. Baseline information on population sizes, densities, ages, age structure, age at sexual maturity, and reproduction dates in BC coastal waters needs to be collected. Other environmental parameters such as geographic location, water temperature and salinity, and predator pressure would provide additional information to help establish a knowledge base about California mussels.

Management options in developing a new fishery are wide ranging. Deciding on which option is the most appropriate is difficult given the lack of concrete data presently known for *M. californianus* populations in BC. Collection of baseline data at this time should be the highest priority of any possible management strategy. No large-scale harvest should be allowed at this point, in order to prevent adverse affects on the populations.

While some harvest or disturbance is likely to have occurred in the past due to aboriginal fisheries, levels and intensity of the harvest is not known. More recently some areas may have been affected by the collection of mussels for the PSP sampling program, although again, no specific data is available for most collection sites. Given the rather isolated and extreme locations of these beds, some could be considered to be in a somewhat natural state. The opportunity exists, then, to establish some very good baseline data on the California mussel populations in BC. It cannot be stressed enough that the collection of this data is essential before any harvest is even considered. The fragile or dynamic nature of the mussel beds needs to be protected, not for future harvest, but for the unique and diverse ecosystem that the beds represent.

6.0 Recommendations

As a result of the review of available literature and other *Mytilus californianus* fishery programs, the following recommendations are presented:

1. Develop an assessment program to ascertain the status of *M. californianus* populations in BC. Collection of information on various populations should include baseline biological data, but more importantly, should include any data that would allow a better understanding of the mussel populations within BC. This may necessitate the development of partnerships with various organizations that would be involved in a future mussel fishery.

2. Establish a long-term program to evaluate harvest methods and their effects on the recruitment and growth of various *M. californianus* populations. This would fall under the second phase (Phase 1) of the guidelines established by Perry (1996) which was designed to increase the stock information.

3. No commercial or pilot harvest should be considered until information on the mussel stocks is analyzed. Results from the surveys may preclude any future harvest for conservation concerns.

4. Water quality testing at the various harvest sites needs to be done. Human health concerns should be a top priority. Even though a commercial harvest may not be allowed, the sport harvest is likely to continue and health concerns need to be addressed.

5. Consultation with First Nations to avoid future conflict as well as to gather information on historical practices.

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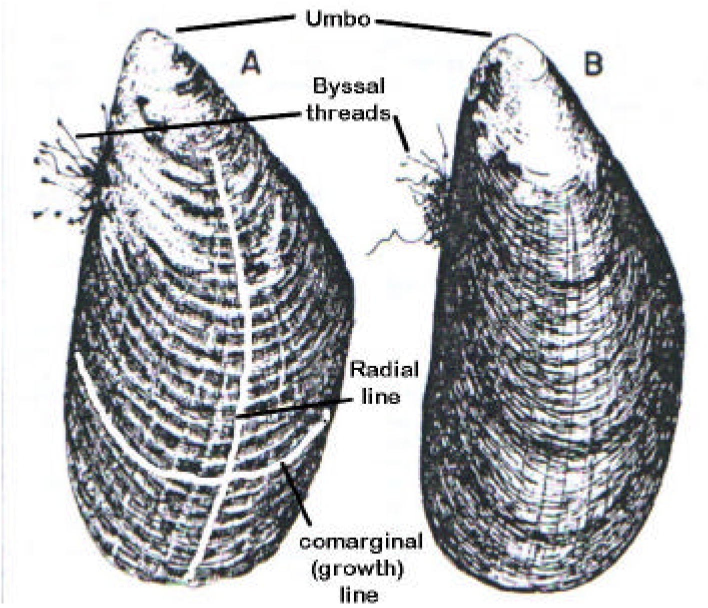

Figure 1: Shells of the California Mussel (A) and the bay mussel (B). Note the stronger comarginal growth lines, prominent radial lines, slightly thicker byssal threads and general rougher appearance of the California mussel. (Adapted from Shaw et al. 1998).

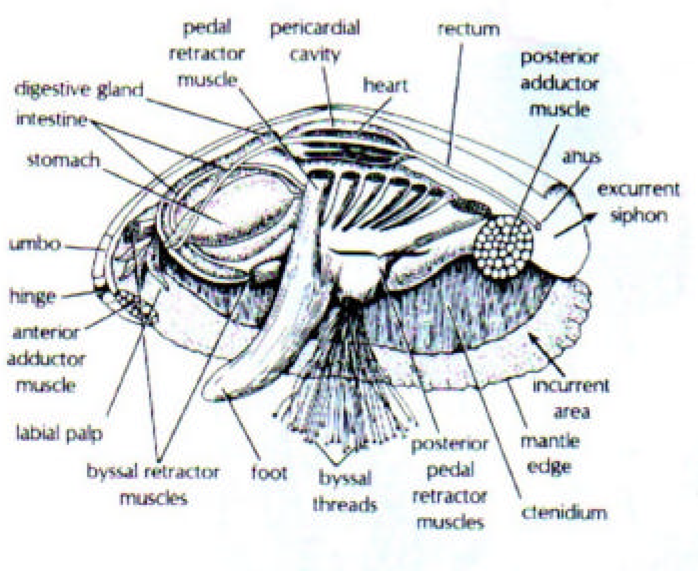

Figure 2: General anatomy of a mussel. (Adapted from Pechenik 1996).

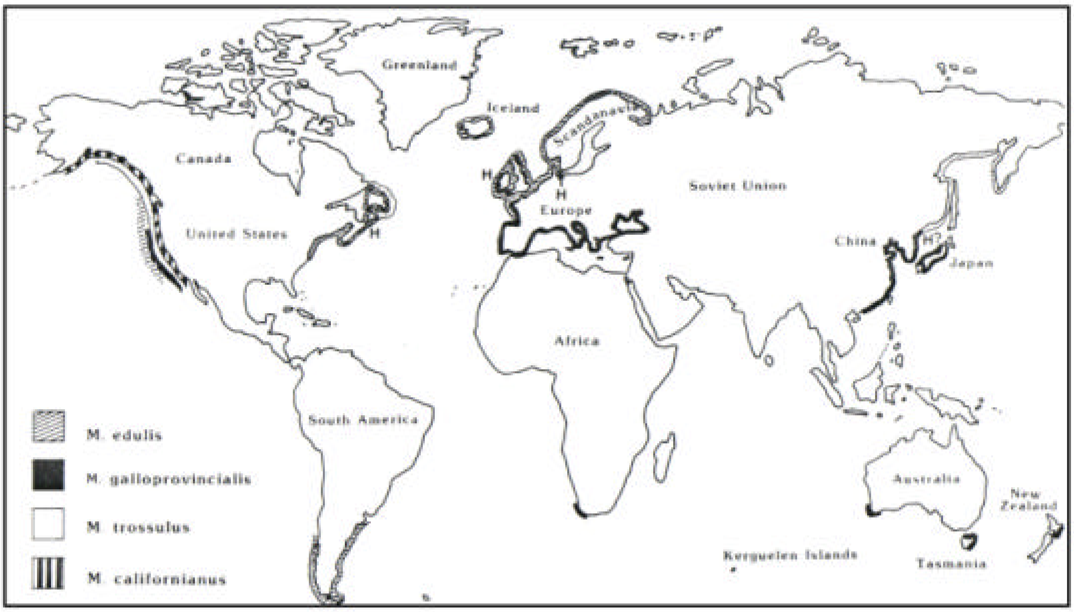

Figure 3: Distribution of the California mussel and related species worldwide. (Adapted from Gosling 1992).

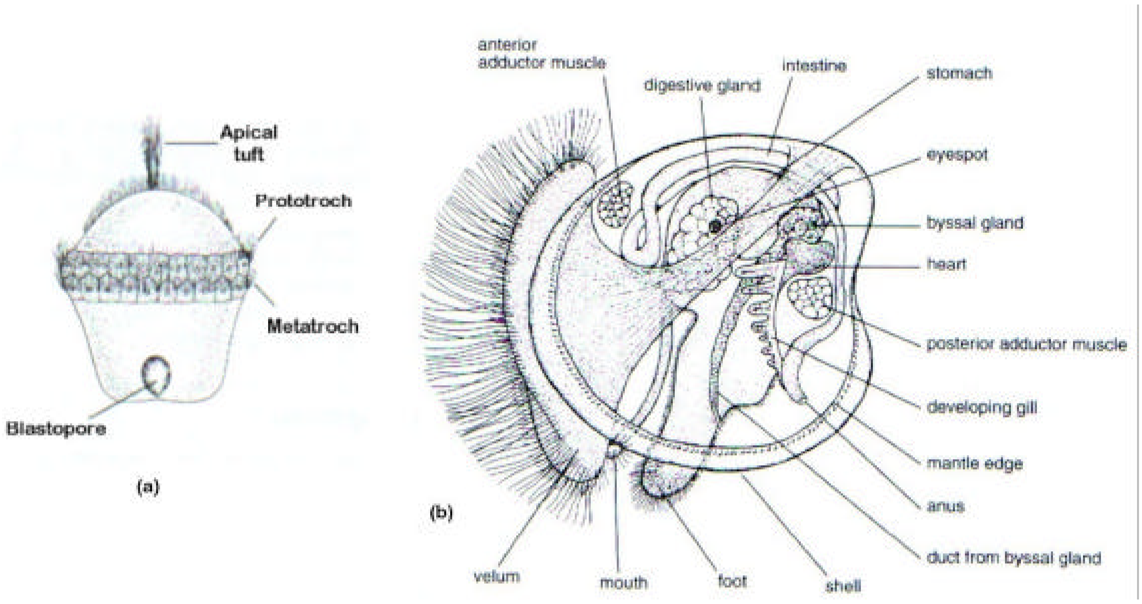

Figure 4: Typical trochophore (a) and veliger (b) larval stages. (Adapted from Pechenik 1996).

Table 1: Annual mortality rates of *Mytilus edulis* as calculated by Seed (1976) in the Danish Sea.

Shell Length (mm)	Annual Mortality Rate
25	0.6757
30	0.5631
40	0.4223
50	0.3379

Table 2: Predators of *M. californianus*. (Seed and Suchanek 1992; Seed 1976)

Starfish – Mainly *Pisaster ochraceus* but also *P. giganteus, Lepasterias hexactis , Picnopodia helianthoides*
Crabs
Whelks – *Nucella emarginata, Nucella canaliculata*
Other gastropods
Fish – ie flounder
Mammals – sea otters (*Enhydra lutris*), Pinnipeds
Birds – Gulls (*Larus* spp.) and oystercatchers (*Haematopus bachmani*)

Table 3: Commercial catch statistics for *M. californianus* and *M. edulis (M. trossulus)*. Weights for both species are combined (from ODFW annual reports 1988-1997).

Year	Round Weight (lbs)	Round Weight (Kg)
1979	19,068	8,667
1980	60,629	27,559
1981	17,866	8,121
1982	18,372	8,351
1983	28,267	12,849
1984	36,198	16,454
1985	40,168	18,258
1986	37,494	17,042
1987	48,903	22,229
1988	50,656	23,025
1989	65,048	29,567
1990	44,445	20,202
1991	31,931	14,514
1992	22,472	10,215
1993	22,934	10,425
1994	20,009	9,095
1995	25,702	11,683
1996	2,756	1,253
1997	1,919	872

Table 4: Yearly Landings of Mussels in California (From Shaw et al. 1988).

Year	Landings (lbs)	Landings (Kg)	Year	Landings (lbs)	Landings (Kg)
1916	53,799	24,454	**1932**	230	105
1917	69,042	31,383	**1933**	465	211
1918	19,154	8,706	**1935**	10	5
1919	35,095	15,952	**1936**	750	341
1920	33,112	15,051	**1937**	1,490	677
1921	9,196	4,180	**1938**	150	68
1922	43,872	19,942	**1939**	1,800	818
1923	60,026	27,285	**1940**	100	45
1924	49,223	22,374	**1942**	50	23
1925	25,942	11,792	**1946**	639	290
1926	14,614	6,643	**1947**	530	241
1927	29,631	13,469	**1972A**	111,799	50,818
1928	1,610	732	**1974A**	81,642	37,110
1929	1,028	467	**1975A**	53,691	24,405
1930	325	148	**1976B**	47,336	21,516
1931	1,800	818			

A - Bait

B - 2437 lbs for human consumption, rest for bait.