COSEWIC
Assessment and Status Report

on the

Olympia Oyster
Ostrea lurida

in Canada

SPECIAL CONCERN
2011

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Previous report(s):

COSEWIC. 2000. COSEWIC assessment and status report on the Olympia Oyster *Ostrea conchaphila* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 30 pp. (www.sararegistry.gc.ca/status/status_e.cfm)

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Olympia Oyster — Provided by author.

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COSEWIC
Assessment Summary

Assessment Summary – May 2011

Common name
Olympia Oyster

Scientific name
Ostrea lurida

Status
Special Concern

Reason for designation
This species is the only native oyster along the Pacific coast of Canada. Although its population suffered large-scale historical declines associated with overharvest, it appears to have been stable in recent decades. However, recent introductions of exotic parasites, predatory snails, green crabs and fouling ascidians, as well as industrial and domestic pollution, pose significant threats to the oyster. Limited dispersal and vulnerability to low temperature extremes and sedimentation from floods and landslides may increase its vulnerability and ability to recover from adverse impacts.

Occurrence
British Columbia, Pacific Ocean

Status history
Designated Special Concern in November 2000 and in May 2011.

COSEWIC
Executive Summary

Olympia Oyster
Ostrea lurida

Wildlife species description and significance

The Olympia Oyster, *Ostrea lurida* (previously *Ostrea conchaphila*), is a small oyster with a shallowly cupped lower (left) shell and a flat upper (right) shell that fits within the margins of the lower shell. The maximum size is approximately 90 mm diameter, though most individuals are smaller. They are often attached to hard substrate, but may occur unattached or in clusters with other individuals. The shell is more or less elliptical in outline and white to purplish-black on the outer surfaces; the inner surfaces are white to iridescent green to purple. The adductor muscle scar is similar in colour to the rest of the inside of the shells.

The Olympia Oyster is a species that served as a source of food for indigenous peoples, supported commercial and recreational fisheries post-contact, and has become valued for their historic role and ecosystem services, influenced in part by the intense interest in habitat rehabilitation along the west coast of the U.S.

Distribution

The Olympia Oyster is the only oyster native to British Columbia. It is found only on the west coast of North America, between Gale Passage, British Columbia (~52ºN) and Baja California, Mexico (~30ºN). Specific habitat requirements limit dense aggregations to relatively few places. Although historically reported from Sitka, recent occurrence in Alaska has not been confirmed. In Canada, the species is known from the Strait of Georgia, the west coast of Vancouver Island, and from a few sites in Queen Charlotte Strait and the coastal mainland of Queen Charlotte Sound on B.C.'s Central Coast.

Habitat

Olympia Oysters are found primarily in the lower intertidal and shallow subtidal zones of estuaries and saltwater lagoons. They have also been found on tidal flats, in splash pools, near freshwater seepage, in tidal channels, bays and sounds, or attached to pilings or the undersides of floats.

Biology

Olympia Oysters are sedentary, filter feeding on plankton. Reproduction is closely linked to temperature and spawning occurs in summer. Sexual maturity is achieved at approximately one year of age in B.C. Olympia Oysters mature first as males, then alternate sexes for the remainder of their life. Eggs are fertilized in the mantle cavity using sperm collected in the respiratory current. The eggs are carried in the mantle of the female for 14–17 days, and the resulting larvae are released into the water column, where they drift and feed (as planktotrophic larvae) for another two to three weeks, then settle on hard substrates. Brood size is approximately 250,000 to 300,000 eggs per female. Maximum life span is unknown, but there is evidence that it exceeds 10 years. Olympia Oysters are not motile as adults and the planktonic larval stage offers the only opportunity for species' dispersal. Olympia Oysters exhibit little specific behaviour other than feeding, reproduction, and selection of a settlement site.

Population sizes and trends

Quantitative estimates of Olympia Oyster populations, either historical or recent, are not generally available. Anecdotal evidence indicates that current population levels in the Strait of Georgia are low relative to historical levels. Major declines in population occurred during a period of fisheries exploitation between the late 1800s and 1930. The decline was primarily due to depletion of large concentrations from specific sites. Small populations with low densities still exist in the Strait of Georgia; on the west coast of Vancouver Island, oysters are locally common and abundant at more sites. There are no data on population trends, but populations appear to persist at low levels

Threats and limiting factors

The small but unsustainable commercial fishery has been implicated in the decline of Olympia Oysters in Canada. Harvest is now likely a negligible threat, but as explained below, the Pacific Oyster fishery may have exacerbated other, still ongoing threats. It is possible that the species' population dynamics and productivity are not resistant to human harvests on any commercial scale.

British Columbia represents the effective northern limit of the Olympia Oyster. This species is vulnerable to environmental extremes, and low winter temperatures are likely a contributing factor to limiting distribution. Increasing incidence and intensity of extreme weather events in the future could threaten intertidal individuals.

Olympia Oysters fall prey to crabs, snails, sea stars, and birds. The introduced European Green Crab is a significant predator on intertidal bivalves and has shown preference for Olympia Oysters in laboratory experiments. The effect of this new predator, whose current range includes sites with high densities of Olympia Oysters on the west coast of Vancouver Island, has not been quantified. Olympia Oysters are preyed upon by non-indigenous marine snails, but the limited distribution and dispersal capacity of these gastropods renders them less of a threat. Non-indigenous fouling organisms, particularly ascidians, present a threat to survival of juvenile Olympia Oysters.

The role of human alteration of habitat on Olympia Oyster numbers, particularly in sensitive estuarine habitats, has not been thoroughly examined, but there is evidence that cumulative effects of urbanization, sedimentation, log storage, bark decay, dredging and deposition of dredge spoils, diking, filling, domestic and industrial pollution all contributed to the decline of Olympia Oysters in Coos Bay, Oregon. The same factors may be contributing to lack of recovery to historical levels at some B.C. sites. There is evidence that pulp mill pollution caused declines of Olympia Oysters in Puget Sound. There is also documentation of reproductive failure of closely related European species due to the effects of anti-fouling compounds.

Hypotheses regarding the role of marine shellfish aquaculture in poor recovery of Olympia Oyster numbers include incidental mortality of Olympia Oysters attached to harvested Pacific Oysters and poor survival of Olympia Oysters settling on Pacific Oyster shell in the mid- to upper-intertidal zone, rather than low intertidal and subtidal zones.

Some members of the U.S. oyster industry believe that disease played a role in the collapse of some Olympia Oyster stocks. Denman Island disease (*Mikrocytosis mackini*, a microcell disease of Pacific Oyster) could be a contributing factor to low population levels.

Protection, status, and ranks

Olympia Oysters were assessed as Special Concern by COSEWIC in 2000 and listed as a Special Concern species under SARA in 2003. Current commercial and recreational oyster fisheries in British Columbia are limited to the introduced Pacific Oyster. There is little recreational interest in harvesting Olympia Oysters and the daily bag limit has been set at zero.

Olympia Oysters have been placed on the provincial blue list of Special Concern species by the B.C. Conservation Data Centre. They are not listed by the International Union for Conservation of Nature and Natural Resources (IUCN), nor are they listed under Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) agreements.

TECHNICAL SUMMARY

Ostrea lurida
Olympia Oyster — Huître plate du Pacifique
Range of occurrence in Canada: British Columbia/Pacific Ocean

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used) *Possibly approaching 10 years*	Unknown
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Inferred stable
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future. *Populations appear stable*	No
Are the causes of the decline clearly reversible and understood and ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence *Area of minimum convex polygon encompassing all verified occurrences, clipped to exclude extralimital area outside Canadian jurisdiction (Wu pers. comm. 2009)*	66,835 km²
Index of area of occupancy (IAO) *Total of 138 2 × 2 km grids occupied by verified sites converted to area (Wu pers. comm. 2009)*	552 km²
Is the total population severely fragmented? Sites are restricted to appropriate habitat (lower intertidal and subtidal zones of specific beaches); these habitat patches are relatively closely aggregated geographically in southern B.C., but are isolated in northern B.C.	No
Number of "locations*"	>10
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	Unknown
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	Unknown
Is there an [observed, inferred, or projected] continuing decline in number of populations?	Unlikely
Is there an [observed, inferred, or projected] continuing decline in number of locations?	Unlikely
Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat?	Unknown
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations*?	No

* See definition of location.

Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Total	>3,000,000

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not available

Threats (actual or imminent, to populations or habitats)

- **Environmental extremes**: the species cannot withstand freezing; sedimentation from floods and landslides
- **Introduced predators**, including predatory snails and Green Crabs
- **Introduced fouling organisms**, such as ascidians, that compete for appropriate substrate for larval settlement
- **Human alteration of habitat**: urbanization and modification of estuaries; other effects of commercial activities (log dumps and storage); sedimentation from upland uses (agriculture and forestry), filling or dredging
- **Disease**, such as Hexamitiasis or Denman Island Disease
- **Pollution**: domestic pollutants (urbanization); industrial pollutants (primarily kraft pulp mill effluent) which has been linked to significant declines in Puget Sound; and tributyl tin (TBT) from antifouling paints
- **Marine shellfish aquaculture**: possible reduced survival in areas with high density shellfish aquaculture

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? U.S.: candidate for consideration as Species of Concern (Washington)	
Is immigration known or possible? *Immigration is possible only from the closest sites (Puget Sound and possibly Willapa Bay or Grays Harbor) because of larval dispersal periods and patterns. Although this type of immigration could take a long time to occur it would probably only benefit the west coast of Vancouver Island. In summary, immigration may be possible, but at a low rate*.	Possible
Would immigrants be adapted to survive in Canada? *The oysters in Puget Sound are likely best adapted to conditions in the Strait of Georgia; those from outer coastal Washington may be well adapted to conditions on the west coast of Vancouver Island*	Possible
Is there sufficient habitat for immigrants in Canada? *Sufficient habitat is available in some areas of British Columbia for immigrants, but habitat restoration may be required to ensure that immigrants survive.*	Yes
Is rescue from outside populations likely? *The results of molecular analyses indicate that there are measurable genetic differences between Olympia Oysters from Washington and British Columbia, leading analysts to suggest that Canadian populations may have arisen as glacial relicts*.	Possible

Current Status

COSEWIC: Special Concern (2000 and 2011) SARA: Special Concern (2003)

Status and Reasons for Designation

Status:	**Alpha-numeric code:**
Special Concern	Not Applicable
Reasons for designation: This species is the only native oyster along the Pacific coast of Canada. Although its population suffered large-scale historical declines associated with overharvest, it appears to have been stable in recent decades. However, recent introductions of exotic parasites, predatory snails, green crabs and fouling ascidians, as well as industrial and domestic pollution, pose significant threats to the oyster. Limited dispersal and vulnerability to low temperature extremes and sedimentation from floods and landslides may increase its vulnerability and ability to recover from adverse impacts.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable
Criterion B (Small Distribution Range and Decline or Fluctuation): Almost meets IAO threshold for Threatened but number of locations >10
Criterion C (Small and Declining Number of Mature Individuals): Not applicable
Criterion D (Very Small or Restricted Total Population): Exceeds criteria with much more than 10 locations
Criterion E (Quantitative Analysis): Not available

PREFACE

Since the original status report for Olympia Oyster (COSEWIC 2000), surveys have confirmed the persistence of sites supporting oysters and provided preliminary density estimates (Gillespie *et al.* 2004; Gillespie and Bourne 2005a,b; Stanton *et al.* in prep.) and some quantitative surveys have been published (Norgard *et al.* 2010). In addition, Polson *et al.* (2009) provided evidence that *Ostrea lurida* was the correct name for native oysters found on the Pacific coast of North America; the previously used name, *O. conchaphila,* refers instead to a separate species occurring farther south.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2011)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

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The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and classification

Scientific name: *Ostrea lurida* Carpenter, 1864
English common name: Olympia Oyster
French common name: Huître plate du Pacifique

The current classification (Polson *et al.* 2009; Bieler *et al.* 2010) is:

Phylum Mollusca
- Class Bivalvia Linnaeus, 1758
  - Subclass Antobranchia Grobben, 1894
    - Superorder Pteriomorphia Beurlen, 1944
      - Order Ostreioda Férussac, 1822
        - Suborder Ostreina Férussac, 1822
          - Superfamily Ostreoidea Rafinesque, 1815
            - Family Ostreidae Rafinesque, 1815
              - Subfamily Ostreinae Rafinesque, 1815
                - Tribe Ostreini Rafinesque, 1815
                  - Genus *Ostrea* Linnaeus, 1758
                    - *Ostrea lurida* Carpenter, 1864

Of the five oyster species found in British Columbia, the Olympia Oyster, *Ostrea lurida*, is the only native species (Bourne 1997; Coan *et al.* 2000).[*]

[*]Atlantic Oysters, *Crassostrea virginica*, were introduced near Victoria in about 1883 (Carlton and Mann 1996), followed by other introductions at Boundary Bay, Esquimalt and Ladysmith (Quayle 1969). Pacific Oysters, *Crassostrea gigas*, were first introduced to British Columbia in 1912 or 1913, but not in large numbers until 1925 (Elsey 1933; Bourne 1997). More recently, Kumamoto Oysters, *Crassostrea sikamea*, and European Flat Oysters, *Ostrea edulis*, have been intentionally introduced for aquaculture. Pacific Oysters are sporadically able to breed successfully in the southern waters and are firmly established in Georgia Strait and on the west coast of Vancouver Island, partially overlapping the range of Olympia Oysters in B.C. (Gillespie 2007). Atlantic and European Flat Oysters are limited in distribution, with small populations established at the mouth of the Nicomekl River (Boundary Bay, Strait of Georgia) and Barkley Sound, respectively. Kumamoto Oysters have been introduced for aquaculture in southern B.C., but have not become established in the wild.

Historically, the Olympia Oyster was known by the name *Ostrea lurida* Carpenter, 1864, but Harry (1985) synonymized *O. lurida* with *Ostreola conchaphila* (Carpenter, 1857). Coan *et al.* (2000) felt that *Ostreola* was not sufficiently different from *Ostrea* to warrant separating the two genera; this is supported by recent molecular studies (e.g., Kirkendale *et al.* 2004; Lapègue *et al.* 2006; Shilts *et al.* 2007) and Turgeon *et al.* (1998) supported this arrangement. Nevertheless, there is currently only one genus, *Ostrea*. Polson *et al.* (2009) provided molecular evidence that *O. lurida* and *O. conchaphila* are distinct species. Consequently, *O. lurida* is again considered the correct name for native oysters north of central Baja California. *Ostrea lurida* and *O. conchaphila* are morphologically indistinguishable (see **Population Sspatial structure and variability**) (Polson *et al.* 2009). Phenotypic plasticity, varied habitats where specimens were collected, and the taxonomic tendencies of early naturalists have led to a long list of synonymy (see Coan *et al.* 2000).

The Manhousat people called the Olympia Oyster tl’uux̲wtl’ux̲w, perhaps derived from tl’ukw (‘wide’) or puukw7istl’uk̲w (‘thin and flat’), either of which describe the shell shape (Ellis and Swan 1981). The various English common names reflect either preferred habitats (e.g., Rock Oyster, Shell-loving Oyster), geography (e.g., Olympia Oyster, California Oyster, Yaquina Oyster, Shoalwater Oyster [Shoalwater Bay was an early name for Willapa Bay, Washington], etc.), or distinguish *O. lurida* from introduced species (e.g., Native Oyster). The name recognized by the American Fisheries Society is Olympia Oyster (Turgeon *et al.* 1998). The term “native oyster” is commonly used to refer to *O. lurida* in areas other than Puget Sound. The French name for the species is Huître plate du Pacifique.

Formal ATK information was not available at the time this report was prepared (D. Benoit, pers. comm.).

Morphological description

Olympia Oysters are small, irregularly shaped oysters, tending to be more or less elliptical or circular (Figure 1). The valves (shells) are thin and not chalky as in *Crassostrea*. The valves are unequal, with the lower (left) valve shallowly cupped, and the upper (right) valve generally flat, fitting into the raised margin of the lower valve. The lower valve is often attached to a hard substrate, but individuals may be found lying freely on soft substrate, either singly or in clusters with other individuals. Free-living individuals often exhibit small scars on the lower valve indicating the original point of attachment. The outer surface of the valves may be grey, grey blotched with purple, white, brown, yellow or purplish black; the inner surface grades from white to iridescent green to dark purple. The adductor muscle scar differs little in colour from the rest of the inner surface, unlike the darker scars present in Atlantic Oysters (*Crassostrea virginica*) or Pacific Oysters (*C. gigas*). The triangular ligament is internal. The shells exhibit a series of 2–12 pits in the lower valve on either side of the hinge (catachomata), with associated denticles in the upper valve (anachomata); these chomata sweep from the ligament to <50% of the distance to the ventral margin unlike tropical oysters of the genus *Saccostrea*, in which the chomata sweep the entire distance to the ventral margin. Both left and right pryomyal chambers are closed (as opposed to *Crassostrea*, in which the right pryomyal chamber is open). Juveniles may have a thin yellow periostracum, which is lacking in adults. After settlement, oysters lack a foot typical of clams and byssus typical of mussels (Quayle 1969; Kozloff 1974; Harry 1985; Couch and Hassler 1989; Baker 1995; Harbo 1997; Polson *et al.* 2009).

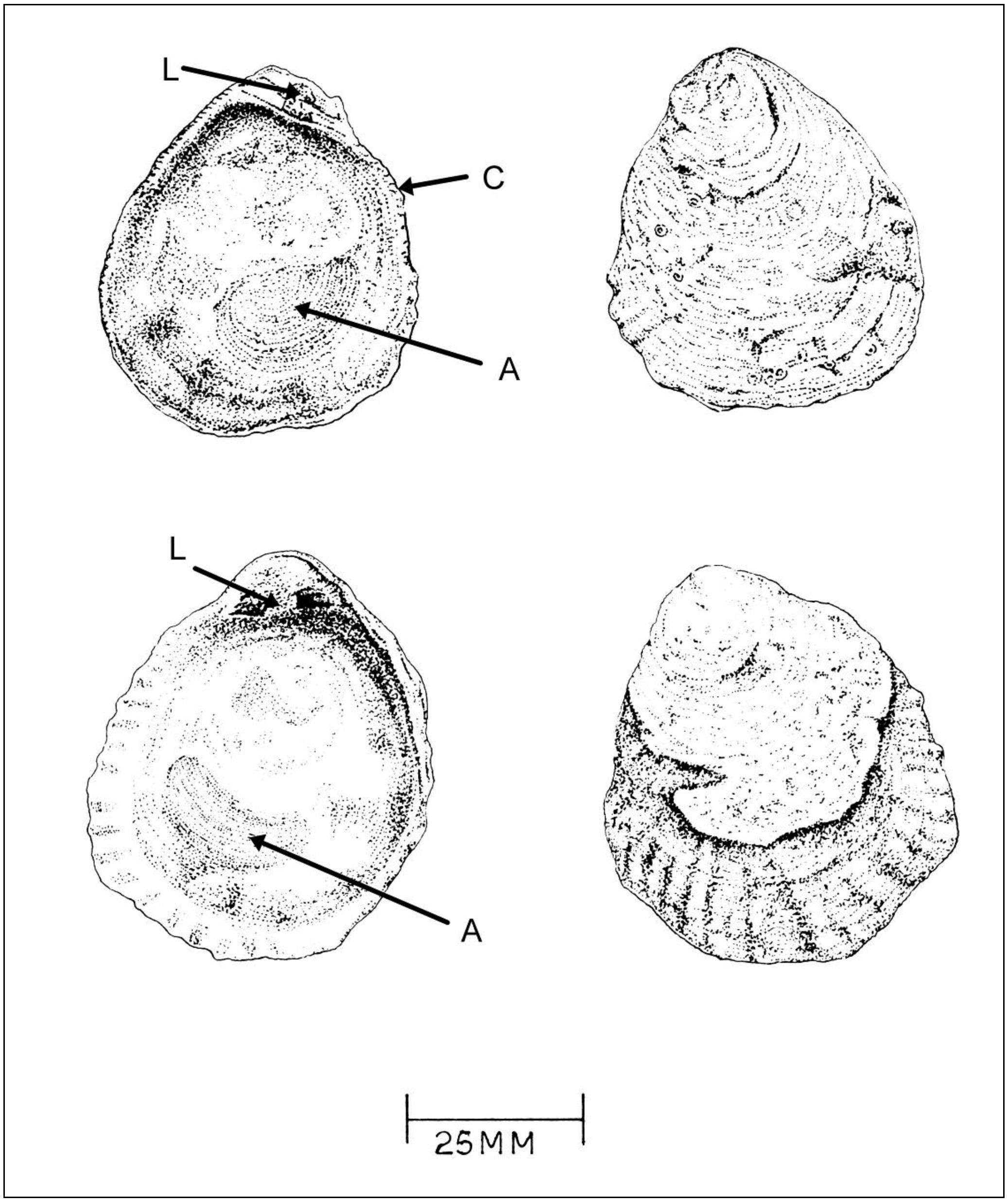

Figure 1. The Olympia Oyster, *Ostrea lurida*. Legend: Top row is upper (right) valve, bottom row is lower (left) valve; left column is inner surfaces, right column is outer surfaces. A – adductor muscle scar; C – chomata; L – ligament.

The maximum size is approximately 90 mm in diameter (Harbo 1997), but individuals in British Columbia generally are 60 mm or less in diameter (Gillespie *et al.* 2004; Gillespie and Bourne 2005a; Gillespie 2009). Individuals from Puget Sound, Washington and California are generally of a smaller size (Baker 1995).

Population spatial structure and variability

Polson *et al.* (2009) used mitochondrial DNA alleles at the CO3 and 16S loci and 22 outgroup sequences downloaded from GenBank to examine inter- and intra-specific variation of oysters from British Columbia to Bahía de Kino, Sonora, Mexico. Two sites were sampled in Canada and 17 sites on the outer coast from Willapa Bay, Washington, to Baja California. Polson *et al.* were able to separate two taxa, *O. lurida* in the north and *O. conchaphila* from Ensenada de Pabellón, Mexico. Interestingly, Canadian samples from Ladysmith Harbour (Strait of Georgia) and Ahmah Island (Barkley Sound) were identical to each other and distinct from oyster samples from Pacific US states (Willapa Bay, Washington to Bahía de San Quintín, Baja California), leading the authors to speculate that British Columbia sites may be relicts from Pleistocene glacial refugia.

Designatable units

Because fine scale molecular studies have not been attempted on Olympia Oysters in Canada and the inference that Canadian samples from inner and outer coastal waters are indistinguishable from each other (Polson *et al.* 2009), there is only one designatable unit.

Special significance

Of the four species of oyster currently found in British Columbia, the Olympia Oyster is the only native species. Olympia Oysters were utilized by some First Nations people for food, and shells were used as ornamentation (Harbo 1997). The Manhousat people occasionally gathered Olympia Oysters for food, then steamed them in a pit or boiled them; only the adductor muscle was eaten and the remaining juice after boiling was drunk like tea. Olympia Oysters were a source of food for Aboriginal peoples in Washington, Oregon and California, and oyster populations may have declined before historic times based on relative frequency in middens (Shaw 1997; Groth and Rumrill 2009; White *et al.* 2009b).

The Olympia Oyster supported a small commercial fishery in Canada, beginning approximately in 1884 and continuing to about 1930 when natural oyster beds had become exhausted and the fishery switched to larger, more marketable introduced species. The Olympia Oyster is now valued for historic significance and its water filtration and habitat engineering roles in the ecosystem; there is intense interest in the rehabilitation of the species in the Pacific U.S. states (e.g., Brumbaugh and Coen 2009).

DISTRIBUTION

Global range

Olympia Oysters are found only on the west coast of North America (Figure 2). When considered conspecific with *Ostrea conchaphila*, the range was believed to extend from Sitka, Alaska (*ca.* 57°N) to Panama (*ca.* 9°N) (Harbo 1997; Coan *et al.* 2000). The northern limit was based on a record by Dall (1914, 1916) and is suspect. However, northern and southern populations now represent two different species, *O. lurida* and *O. conchaphila*, respectively (Polson *et al.* 2009; see **Name and classification**). Polson *et al.* (2009) indicated that the southern limit of *Ostrea lurida* is Bahía de San Quintín, Baja California (*ca.* 30°N), although they lacked samples between this site and the previously reported southern limit of Cabo San Lucas, Baja California (*ca.* 24°N) (Haderlie and Abbott 1980; Coan *et al.* 2000). Although generally distributed, specific habitat requirements limit sites where oysters are abundant to relatively few places (Galtsoff 1929). Large numbers of Olympia Oysters still occur in some appropriate habitats in the lower western United States (Baker 1995; Robinson 1997; Shaw 1997; Dinnel *et al.* 2009; Groth and Rumrill 2009).

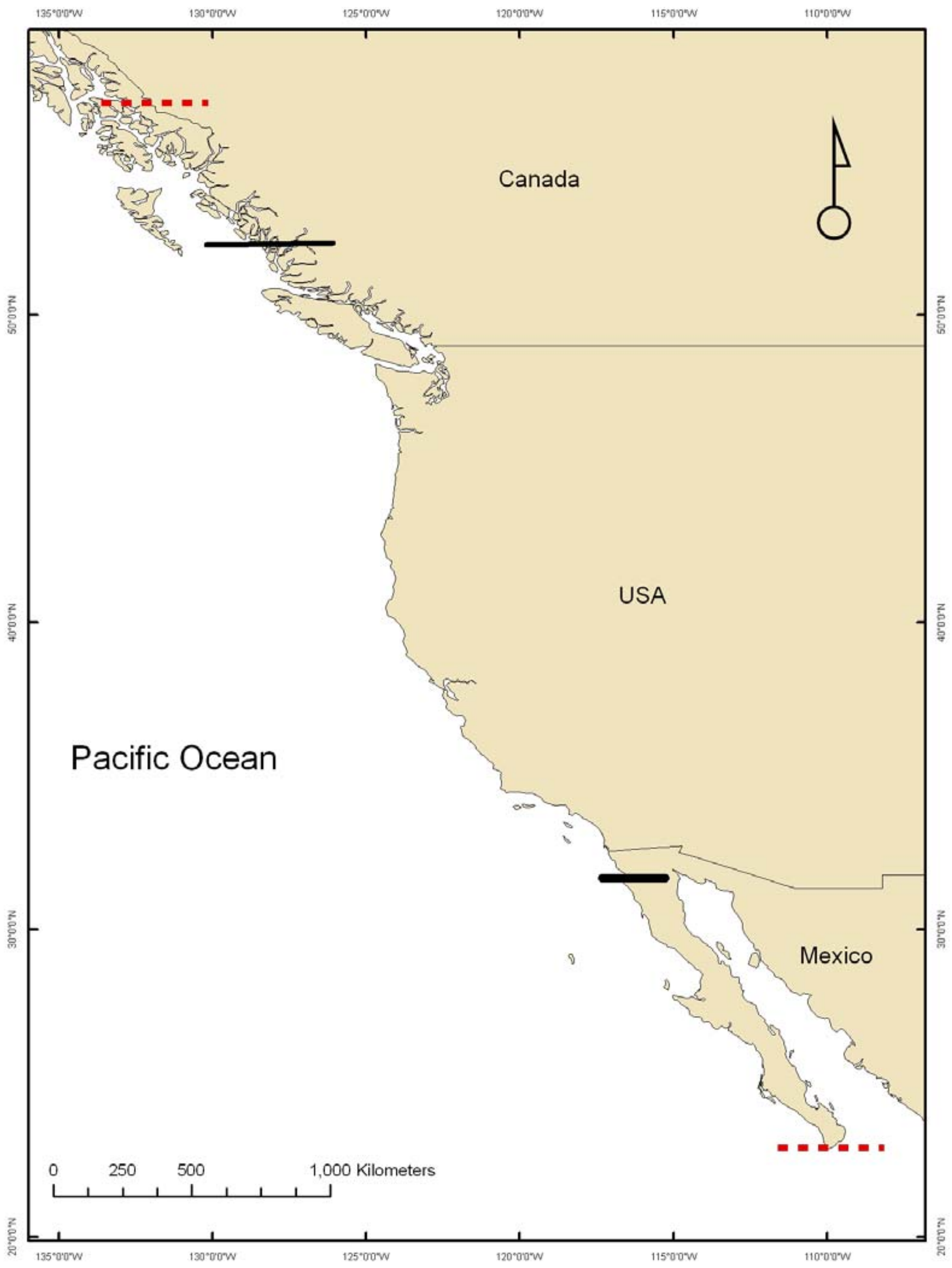

Figure 2. Worldwide distribution of Olympia Oyster, *Ostrea lurida*. Dotted lines represent historic latitudinal limits (Sitka, Alaska and Cabo San Lucas, Mexico) and solid lines represent currently verified latitudinal limits (Gale Passage, British Columbia and Bahía de San Quintín, Mexico).

Olympia Oysters were historically reported from Southeast Alaska, but were seldom encountered in dense aggregations, nor were specific sites reported (Paul and Feder 1976). Their presence in Alaska is unsubstantiated despite investigation (Foster 1991; Gillespie 2009; Polson and Zacherl 2009). Shells provided to Dall may have come from semi-fossil shell beds like those documented by Steele (1957), Sutherland Brown (1968), and Trimble *et al.* (2009) at Juneau (Alaska), Tasu Sound (Haida Gwaii [Queen Charlotte Islands]), and Willapa Bay (Washington), respectively. The semi-fossil beds still exist at Flat Creek in Tasu Sound (Jones pers. comm. 2009) and radiocarbon dates indicate that the deposit is approximately 8,000 years old (Sutherland Brown 1968).

Olympia Oysters were harvested from Willapa Bay and Puget Sound, Washington, in the mid-1850s (White *et al.* 2009b). Historic sites producing Olympia Oysters in North Puget Sound included Orcas, Shaw and Whidbey Islands; and Bellingham, Chuckanut, Fidalgo, Padilla, Samish and Similk bays (Dinnel *et al.* 2009). Recent verifications include Samish Bay and Lopez Sound. Overharvest, adverse environmental conditions and pollution led to population declines and a shift in the industry to use of Pacific Oysters. Olympia Oysters still exist at several sites in Puget Sound, Willapa Bay and Grays Harbor (Baker 1995; Dinnel *et al.* 2009; Polson and Zacherl 2009; Trimble *et al.* 2009; White *et al.* 2009a).

Significant numbers of Olympia Oysters were reported by Marriage (1958) only from Yaquina and Netarts Bays, Oregon, but Baker (1995) indicated the species had disappeared from the latter bay. Olympia Oysters were present in Coos Bay, Oregon, in pre-colonial times, as evidenced by their presence in middens (Baker 1995; Baker *et al.* 2000; Groth and Rumrill 2009). The cause of their extirpation from this area is unknown, but potential explanations include excessive sedimentation resulting from a great forest fire that swept the area in 1846 and/or sedimentation from an earthquake and tsunami in 1700 (Edmonson 1923, Dimick *et al.* 1941; Nelson *et al.* 1996; Groth and Rumrill 2009). Several unsuccessful attempts were made to reintroduce Olympia Oysters to Coos Bay beginning in the early 1910s (Edmonson 1923; Baker *et al.* 2000). Recent investigations in Oregon indicate that Olympia Oysters are currently present only in Netarts, Yaquina and Coos bays (Groth and Rumrill 2009).

The early fishery in California was centred in San Francisco Bay, with smaller efforts in Elkhorn Slough, Humboldt, Newport and Tomales Bays. Baker (1995) reported evidence of historical Olympia Oyster sites that had been extirpated (e.g., Big Lagoon, Elkhorn Slough, Mugu Lagoon, Alamitos Bay, Anaheim Bay, Mission Bay, San Diego Bay and Tijuana Lagoon, California). He also listed sites (e.g., Agua Hedionda and Los Pensaquitos Lagoons, California) where addition of breakwaters resulted in the establishment of new habitat. Recent investigations indicate that Olympia Oysters are present in Alamitos, Humboldt, Mission, Newport, San Diego, San Francisco and Tomales Bays; Mugu, Agua Hedionda and Batiquitos Lagoons; and Elkhorn Slough (Polson and Zacherl 2009; Seale and Zacherl 2009).

The ranges of *Ostrea lurida* in Mexico and *O. conchaphila* in Mexico and Central America are not well documented (Baker 1995; Polson *et al.* 2009).

Canadian range

In Canada, Olympia Oysters occur in the Strait of Georgia/Strait of Juan de Fuca, west coast of Vancouver Island, and central B.C. coast (see Figure 3 and **Search effort**). Quayle (1969) indicated that Olympia Oysters might be found in a number of places in British Columbia, but nowhere in abundance. Specific sites where Olympia Oysters occur, or once occurred, are listed in Table 1. The northern verified limit of distribution of Olympia Oysters in Canada (and globally) is Gale Passage (Table 1, Figure 3). Olympia Oysters do not now occur along the North Coast or in Haida Gwaii, although semi-fossil shell beds are known from Tasu Sound, Haida Gwaii (Jones pers. comm. 2009) and Juneau, Alaska (see **Global range**). The southernmost verified sites in Canada are in the Sooke Basin on southern Vancouver Island. The general distribution of Olympia Oysters in southern areas may be greater than indicated simply because oysters living subtidally are rarely observed unless specifically targeted.

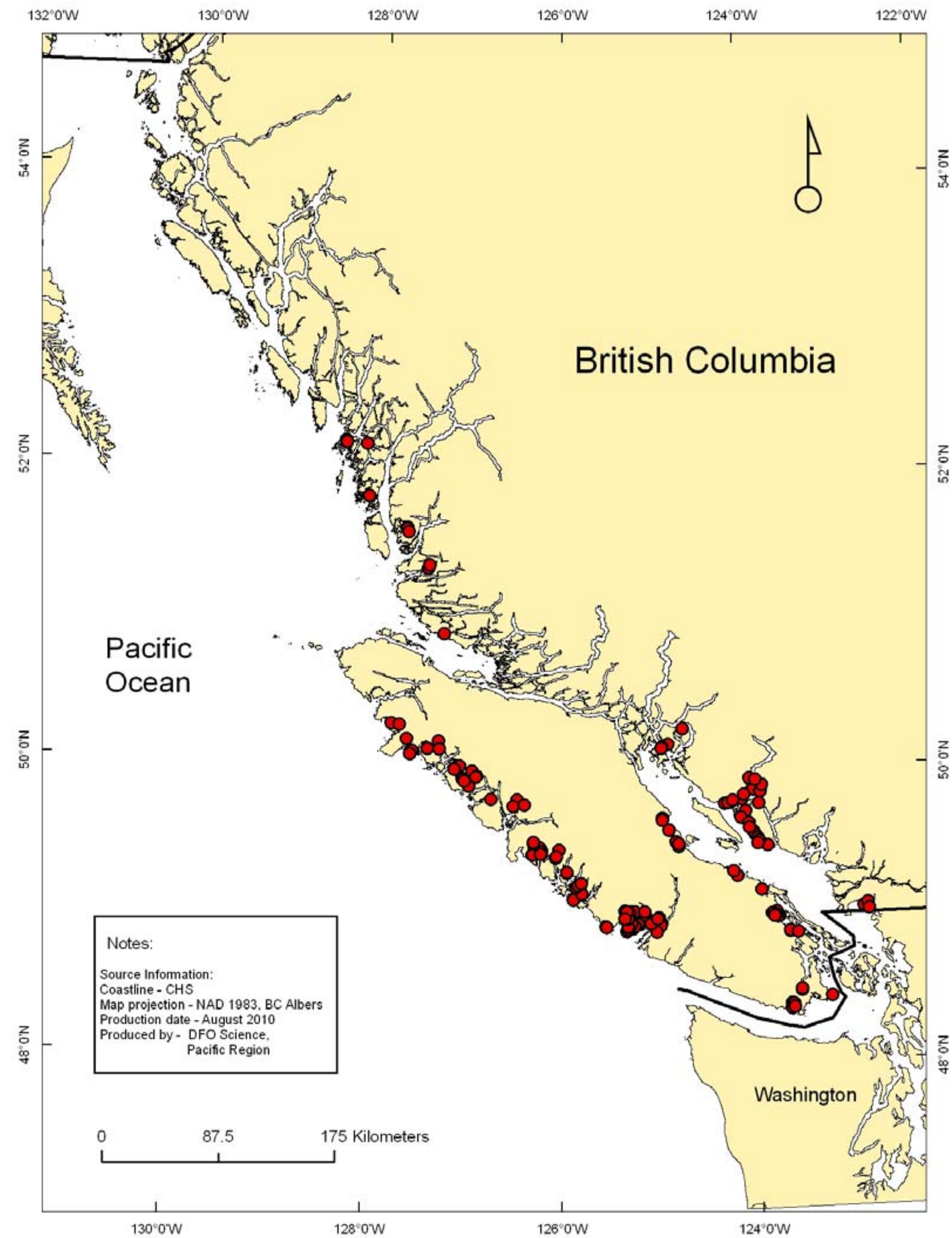

Figure 3. Canadian distribution of Olympia Oyster, *Ostrea lurida*. Dots are sites that have historic reports of Olympia Oysters and verified presence between 1991 and 2009 (see Table 1).

Table 1. Sites in British Columbia where Olympia Oysters, *Ostrea lurida*, have been recorded. Abbreviations: CMNML, Canadian Museum of Nature catalogue number; RBCM, Royal British Columbia Museum catalogue number. "Historic" indicates non-specific records from early literature, "Abundant" indicates classification from citations or numerous specimens in museum collection lots.

Geographic Area	Site	Category	Date	Source
Unknown	Unknown	Present	1967	CMNML 046087
Central Coast				
Milbanke Sound	Bardswell Group	Historic		Elsey (1933)
	Campbell Island	Historic		Quayle (1969)
	Gale Passage	Present	2002	Gillespie (2009)
	Gale Passage	Present	2008	Gillespie (2009)
	Gale Passage	Present	2009	J. Carpenter pers. comm. 2009
	Ormidale Harbour	Present	2007	J. Carpenter pers. comm. 2009
Queen Sound	Watt Bay	Abundant	1991	Bourne *et al.* (1994)
	Watt Bay	Abundant	2004	Gillespie and Bourne (2005b)
	Watt Bay	Abundant	2008	Gillespie (2009)
Fitz Hugh Sound	Fish Egg Inlet	Historic		Elsey (1933)
	Fish Egg Inlet	Abundant	1993	Bourne and Heritage (1997)
	Fish Egg Inlet	Abundant	2000	Gillespie *et al.* (2004)
Smith Inlet	Boswell Inlet	Abundant	2007	Gillespie (2009)
Queen Charlotte Strait				
Queen Charlotte Strait	Blunden Harbour	Historic		Elsey (1933)
	Blunden Harbour	Historic		Quayle (1969)
	Blunden Harbour	Historic		Quayle (1960)
	Blunden Harbour	Historic		Newcombe (1891)
	Bradley Lagoon	Abundant	1885	CMNML 000830
	Bradley Lagoon	Historic		Taylor (1895)
	Bradley Lagoon	Present	2000	Gillespie (2009)
West Coast Vancouver Island				
Quatsino Sound	Unknown	Historic		Elsey (1933)
Brooks Bay	Klaskino Inlet	Abundant	2001	Gillespie *et al.* (2004)
	Klaskino Inlet	Abundant	2002	Gillespie and Bourne (2005a)
	Klaskino Inlet	Abundant	2007	Gillespie (2009)
	Klaskino Anchorage	Present	2007	Gillespie (2009)
	Klaskish Basin	Present	1975	Ellis and Emerson (1979)
Checleset Bay	Bunsby Islands	Present	1975	Ellis and Emerson (1979)
	Cuttle Islets	Present	1978	Ellis and Emerson (1979)
	Johnson Lagoon	Present	1975	Ellis and Emerson (1979)
	Johnson Lagoon	Present	2000	Gillespie (2009)
	Malscope Inlet	Abundant	2007	Gillespie (2009)
	Ououkinsh Inlet	Present	2002	Gillespie and Bourne (2005a)
Kyuquot Sound	Amai Inlet	Abundant	1995	Kingzett *et al.* (1995b)
	Amai Inlet	Abundant	2002	Gillespie and Bourne (2005a)
	Cachalot Inlet	Abundant	2002	Gillespie and Bourne (2005a)
	Cachalot Inlet	Abundant	2007	Gillespie (2009)

Geographic Area	Site	Category	Date	Source
	Easy Inlet	Present	1967	RBCM 979-07242
	Kashutl River	Present	2007	Gillespie (2009)
Nootka Sound	Canton Creek	Present	1995	Kingzett *et al.* (1995a)
	Espinosa Inlet	Present	2006	Gillespie (2009)
	Hisnit Inlet	Present	2007	Gillespie (2009)
	Inner Mary Basin	Abundant	1995	Gillespie (1999)
	Little Espinosa Inlet	Present	2006	Gillespie (2009)
	Nesook Bay	Present	1995	Kingzett *et al.* (1995a)
	Nesook Bay	Present	2007	Gillespie (2009)
	Port Eliza	Abundant	1995	Kingzett *et al.* (1995a)
	Port Eliza	Abundant	2002	Gillespie (2009)
	Port Eliza 1	Abundant	2009	Stanton *et al.* in prep.
	Port Eliza 2	Abundant	2009	Stanton *et al.* in prep.
	Port Eliza 3	Abundant	2009	Stanton *et al.* in prep.
	Queen Cove	Present	1995	Gillespie (1999)
	Queen Cove	Present	2006	Gillespie (2009)
	Tlupana Inlet	Present	1995	Kingzett *et al.* (1995a)
Clayoquot Sound	Bacchante Bay	Present	2009	Stanton *et al.* in prep.
	Bottleneck Cove	Abundant	2003	Gillespie (2009)
	Bottleneck Cove	Present	2009	Stanton *et al.* in prep.
	Darr Island	Present	2007	Gillespie (2009)
	Darr Island	Present	2009	Stanton *et al.* in prep.
	Heelboom Bay	Present	2006	Gillespie (2009)
	Lemmens Inlet	Present	2006	Gillespie (2009)
	Mosquito Harbour	Abundant	2000	Gillespie *et al.* (2004)
	Mosquito Harbour	Present	2006	Gillespie (2009)
	Pretty Girl Cove	Abundant	2003	Gillespie (2009)
	Pretty Girl Cove	Present	2006	Gillespie (2009)
	Stewardson Inlet 2	Present	2009	Stanton *et al.* in prep.
	Stewardson Inlet 3	Present	2009	Stanton *et al.* in prep.
	Sulphur Passage	Possibly present		Gillespie (2009)
	Sulphur Passage 3	Present	2009	Stanton *et al.* in prep.
	Sydney Inlet	Abundant	2005–06	Gillespie (2009)
	Sydney Inlet 1	Present	2009	Stanton *et al.* in prep.
	Sydney Inlet 2	Present	2009	Stanton *et al.* in prep.
	Sydney Inlet 3	Present	2009	Stanton *et al.* in prep.
	Sydney River	Present	1976	RBCM 978-00029-015
	Tofino	Present	1926–36	RBCM 976-01228-037
	Whitepine Cove	Present	2002	Gillespie and Bourne (2005a)
	Whitepine Cove	Present	2006	Gillespie (2009)
	Young Bay	Present		Gillespie (2009)
	Young Bay 1	Present	2009	Stanton *et al.* in prep.
	Young Bay 2	Present	2009	Stanton *et al.* in prep.
Barkley Sound	Ahmah Island	Present	1997	Gillespie (1999)
	Alma Russell Island	Present	1997	Gillespie (1999)
	Amphitrite Point	Abundant	1909	CMNML 001265
	Amphitrite Point	Present	1982	RBCM 979-09591

Geographic Area	Site	Category	Date	Source
	Brabant Island	Present	1997	Gillespie (1999)
	Broken Group	Present	1999	Gillespie (1999)
	Congreve Islands	Present	1997	Gillespie (1999)
	Congreve Islands	Present	2009	Stanton *et al.* in prep.
	Effingham Inlet	Abundant	1997	Gillespie (1999)
	Fatty Basin	Present		Gillespie (2009)
	Harris Point	Abundant	1997	Gillespie (1999)
	Harris Point	Abundant	2009	Stanton *et al.* in prep.
	Hillier Island	Abundant	2002	Gillespie and Bourne (2005a)
	Hillier Island	Abundant	2006–07	Gillespie (2009)
	Hillier Island	Abundant	2009	Stanton *et al.* in prep.
	Jacques/Jarvis Lagoon	Present	1973	Gillespie (2009)
	Jacques/Jarvis Lagoon	Present	1997	Gillespie (1999)
	Jacques/Jarvis Lagoon	Present	2006	Gillespie (2009)
	Joes Bay	Present	2006	Gillespie (2009)
	Julia Passage	Abundant	1997	Gillespie (1999)
	Lucky Creek	Abundant	1993	Gillespie (2009)
	Lucky Creek	Abundant	2002	Gillespie and Bourne (2005a)
	Lucky Creek	Abundant	2009	Stanton *et al.* in prep.
	Mayne Bay	Abundant	1997	Gillespie (1999)
	Nettle Island	Present	1997	Gillespie (1999)
	Pinkerton Islands	Present	1997	Gillespie (1999)
	Pipestem Inlet	Abundant	1995	Gillespie (1999)
	Pipestem Inlet	Present	2006	Gillespie (2009)
	Ritherdon Creek	Present	2009	Stanton *et al.* in prep.
	San Mateo Bay	Present	2009	Stanton *et al.* in prep.
	Santa Maria Island	Present	2009	Stanton *et al.* in prep.
	Snowden Island	Abundant	1993	Gillespie (1999)
	South Stopper Island	Abundant	2007	Gillespie (2009)
	Toquart Bay	Historic		Elsey (1933)
	Toquart Bay	Present	1997	Gillespie (1999)
	Toquart Bay	Present	2009	Stanton *et al.* in prep.
	Useless Inlet	Abundant	1995	Gillespie (1999)
	Useless Inlet	Present	1961	RBCM 979-02365
	Useless Inlet	Present	2006	Gillespie (2009)
	Vernon Bay	Abundant	1997	Gillespie (1999)
	Vernon Bay	Abundant	2006–07	Gillespie (2009)
Strait of Georgia				
Desolation Sound	Pendrell Sound	Historic		Quayle (1969)
	Pendrell Sound	Present	1975	Heritage *et al.* (1976)
	Pendrell Sound	Present	1976	Heritage *et al.* (1977)
	Pendrell Sound	Present	1971–73	Bourne (1978)
	Pendrell Sound	Present	1974	Bourne and Heritage (1979)
	Pendrell Sound	Present	1977	Heritage and Bourne (1979)
	Pendrell Sound	Present	2007	Gillespie (2009)
Northern Gulf Islands	Talbot Cove	Present	2000	Gillespie (2009)
	Von Donop Inlet	Present	1907?	CMNML 001101

Geographic Area	Site	Category	Date	Source
	Von Donop Inlet	Historic		Quayle (1969)
	Von Donop Inlet	Present	2007	Gillespie (2009)
East Coast	Baynes Sound	Historic		Newcombe (1891)
Vancouver Island	Coffin Point	Present	2009	Stanton *et al.* in prep.
	Comox Harbour	Historic		Quayle (1969)
	Comox Harbour	Present	2009	Stanton *et al.* in prep.
	Comox	Abundant	1885	CMNML 000406
	Evening Cove	Present	2009	Stanton *et al.* in prep.
	Fanny Bay	Historic		Thompson (1914)
	Fanny Bay	Present	2009	Stanton *et al.* in prep.
	Goldstream	Present	1996	Gillespie (2009)
	Goldstream	Present	2009	Stanton *et al.* in prep.
	Kulleet Bay	Present	2010	Stanton *et al.* in prep.
	Kuper Island	Historic		Newcombe (1891)
	Ladysmith Harbour	Historic		Quayle (1960)
	Ladysmith Harbour	Historic		Newcombe (1891)
	Ladysmith Harbour	Historic		Stafford (1913b)
	Ladysmith Harbour	Present	1975	Heritage *et al.* (1976)
	Ladysmith Harbour	Present	1976	Heritage *et al.* (1977)
	Ladysmith Harbour	Present	1998	Gillespie (1999)
	Ladysmith Harbour	Present	2006	Gillespie (2009)
	Ladysmith Harbour	Present	2009	Stanton *et al.* in prep.
	Nanaimo	Present	1999	Gillespie (2009)
	Nanaimo	Present	2008	Gillespie (2009)
	Nanaimo	Present	2009	Stanton *et al.* in prep.
	Nanoose Harbour	Historic		Quayle (1969)
	Nanoose Harbour	Present	1999	Gillespie (2009)
	Nanoose Harbour	Present	2009	Stanton *et al.* in prep.
	Page Point, Ladysmith	Present	2009	Stanton *et al.* in prep.
	Raven Park, Ladysmith	Present	2009	Stanton *et al.* in prep.
	Ship Point	Present	2009	Stanton *et al.* in prep.
	Shoal Islands	Present	2009	Stanton *et al.* in prep.
	Transfer Beach	Present	2009	Stanton *et al.* in prep.
	Union Bay	Present	2009	Stanton *et al.* in prep.
	Vesuvius Bay	Present	2009	Stanton *et al.* in prep.
	Wall Beach	Present	2009	Stanton *et al.* in prep.
Mainland Inlets	Baker Bay	Present	2009	Stanton *et al.* in prep.
	Dacres Point	Present	2010	Stanton *et al.* in prep.
	Fairview Bay	Present	2009	Stanton *et al.* in prep.
	Frolander Bay	Present	2009	Stanton *et al.* in prep.
	Green Bay	Present	2009	Stanton *et al.* in prep.
	Harmony Islands	Present	2010	Stanton *et al.* in prep.
	Hotham Sound	Present	1976	Heritage *et al.* (1977)
	Hotham Sound	Present	1977	Heritage and Bourne (1979)
	Jeddah Point	Present	2009	Stanton *et al.* in prep.
	Jervis Inlet 3	Present	2009	Stanton *et al.* in prep.
	Malaspina Inlet	Historic		Newcombe (1891)

Geographic Area	Site	Category	Date	Source
	McNaugton Point	Present	2009	Stanton *et al.* in prep.
	Quarry Bay	Present	2009	Stanton *et al.* in prep.
	Saint Vincent Bay	Present	2009	Stanton *et al.* in prep.
	Saltery Bay	Present	2009	Stanton *et al.* in prep.
	Sargeant Bay	Present		Lamb and Hanby (2005)
	Sargeant Bay	Present	2009	Stanton *et al.* in prep.
	Samuarez Point	Present	2009	Stanton *et al.* in prep.
	Scardon Islands	Present	2009	Stanton *et al.* in prep.
	Smuggler Cove	Present	2009	Stanton *et al.* in prep.
	S. Thormanby Island	Present	2009	Stanton *et al.* in prep.
	Thunder Point	Present	2009	Stanton *et al.* in prep.
	Whitestone Islands	Present	2009	Stanton *et al.* in prep.
	Wood Bay	Present	2009	Stanton *et al.* in prep.
Vancouver	Vancouver	Present		CMNML 000983
Boundary Bay	Boundary Bay	Historic		Quayle (1960)
	Boundary Bay	Historic		Stafford (1913a, 1913b, 1914, 1915, 1916, 1917)
	Boundary Bay	Present	1997–98	Gillespie (2009)
	Crescent	Present	1933–34	RBCM 975-00794-003
	Crescent Beach	Present	2009	Stanton *et al.* in prep.
	White Rock	Present	2009	Stanton *et al.* in prep.
	White Rock	Present	2009	Stanton *et al.* in prep.
Strait of Juan de Fuca				
Victoria	East Chatham Island	Present	2007	Gillespie (2009)
	Esquimalt Harbour	Historic	*ca.* 1858	Lord, in Carpenter (1864)
	Esquimalt Harbour	Historic	*ca.* 1960	Quayle (1960)
	Gorge Waterway	Historic		Quayle (1969)
	Gorge Waterway	Historic		Newcombe (1891)
	Gorge Waterway	Present	2000	AMR (2000)
	Gorge Waterway	Present	2009	Stanton *et al.* in prep.
Sooke Basin	Anderson Cove	Present	1999	Gillespie (1999)
	Anderson Cove	Present	2009	Stanton *et al.* in prep.
	Ayum Creek	Present	2007	Gillespie (2009)
	Cooper Cove	Present	2009	Stanton *et al.* in prep.
	Hutchinson Cove	Present	1999	Gillespie (1999)
	Hutchinson Cove	Present	2009	Stanton *et al.* in prep.
	Roche Cove	Present	1999	Gillespie (1999)
	Roche Cove	Present	2007	Gillespie (2009)
	Roche Cove	Present	2009	Stanton *et al.* in prep.
	Sooke	Historic		Newcombe (1891)
	Sooke	Present	1945–63	RBCM 976-01210-025

Although there presumably have been a few local extirpations at specific sites (see Table 1) and anecdotal evidence suggests that numbers of individuals in the Strait of Georgia are low compared to historical levels (Gillespie 1999, 2009), particularly in Boundary Bay and Ladysmith Harbour, there probably has not been a significant expansion or contraction of the distribution of Olympia Oysters in Canada. New site records for this oyster are likely the result of increased search effort since the first COSEWIC assessment.

Extent of occurrence

The extent of occurrence (EO) for the Olympia Oyster was calculated using the minimum convex polygon method for the verified range of the species in Canada, clipped within Canada's extent of jurisdiction. Total EO for Olympia oysters in Canada was estimated at 66,835 km^2 (Table 1; Wu pers. comm. 2009). This is slightly less than the total area encompassed in the minimum convex polygon as extralimital range in Washington was excluded.

Index of area of occupancy

The index of area of occupancy (IAO) was calculated as the sum of all 2 x 2 km grids that either contained a verified site or joined closely associated verified sites in areas where general occurrence and abundance were high and lack of verification in intervening areas was likely to represent sampling artefacts. Total IAO was estimated at 138 2 x 2 km grids or 552 km^2. This estimate may be misleading for two reasons: it may overestimate area of occupancy as single occurrences on portions of intertidal beaches are expanded to a minimum of 4 km^2, more if the beach falls into more than one grid; or it may underestimate area of occupancy as the current list of verified sites likely does not include all extant Olympia Oyster sites—oysters living in subtidal or cryptic habitats are easily overlooked.

Number of populations

The distribution in Canada of Olympia Oysters is restricted to specific beaches having appropriate habitat in lower intertidal and subtidal zones. These sites are relatively closely aggregated geographically in the Strait of Georgia and west coast of Vancouver Island but are isolated in northern B.C. It is likely there is genetic exchange between adjacent sites owing to the planktonic larvae but perhaps less exchange between inner and outer coast sites. The larval stage has been described as relatively short with limited capacity for dispersal (Coe 1932b; Baker 1995; see **Dispersal migration**), suggesting multiple populations, but there are no data on the genetic exchange between sites and the number of populations that comprise the total population in Canada is unknown.

Number of locations

Locations are defined as geographically or ecologically distinct areas in which a single threatening event can rapidly affect all individuals of the wildlife species. Central Coast sites may all be grouped together if freezing during exposure at low tide is considered the most likely threat (see **THREATS AND LIMITING FACTORS**). Alteration of habitat, pollution from industrial and urban sources, marine shellfish aquaculture, and non-indigenous predators/competitors (in part, depending on the dispersal ability of the species) are localized threats that suggest multiple locations. This patchwork of localized threats is especially true within the Strait of Georgia. Altogether, the number of locations for this species is greater than 10. Table 2 describes in detail the variety of threats and the different risk levels of the threats at each site and within each region.

Table 2. Risk levels (Low [null], Moderate [+] or High[++]) by Threat and Site for Olympia Oysters, *Ostrea lurida*, in British Columbia, Canada.

		Threat							
Region	**Site**	**Environmental Extremes**	**Non-indigenous Species**	**Urbanization**	**Marine Shellfish Aquaculture**	**Disease**	**Pulp Mill Pollution**	**Site-specific Alterations**	**Harvests**
Central Coast	Gale Passage	++	+						
	Ormidale Harbour	++	+						
	Watt Bay	++	+						
	Fish Egg Inlet	++	+						
	Boswell Inlet	++	+					++	
Queen Charlotte Strait	Blunden Harbour	++	+						
West Coast	Klaskino Inlet	+	++						
Vancouver	Klaskish Basin	+	++						
Island	Bunsby Islands	+	++						
	Cuttle Islets	+	++		+				
	Johnson Lagoon	+	++						
	Ououkinsh Inlet	+	++						
	Amai Inlet	+	++		+				
	Cachalot Inlet	+	++		+				
	Easy Inlet	+	++		+				
	Kashutl River	+	++		+				
	Canton Creek	+	++		+				
	Espinosa Inlet	+	++		+				
	Hisnit Inlet	+	++		+				
	Inner Mary Basin	+	++		+				
	Little Espinosa Inlet	+	++		+				
	Malksope Inlet	+	++		+				
	Nesook Bay	+	++		+				
	Port Eliza	+	++		+			+	
	Queen Cove	+	++		+				
	Tlupana Inlet	+	++		+				
	Bacchante Bay	+	++		+				

Region	Site	Threat							
		Environmental Extremes	**Non-indigenous Species**	**Urbanization**	**Marine Shellfish Aquaculture**	**Disease**	**Pulp Mill Pollution**	**Site-specific Alterations**	**Harvests**
	Bottleneck Cove	+	++		+				
	Darr Island	+	++		+				
	Heelboom Bay	+	++		+				
	Lemmens Inlet	+	++		+				
	Mosquito Harbour	+	++		+				
	Pretty Girl Cove	+	++		+				
	Stewardson Inlet	+	++		+				
	Sulphur Passage	+	++		+				
	Sydney Inlet	+	++		+				
	Whitepine Cove	+	++		+				
West Coast	Young Bay	+	++		+				
Vancouver	Ahmah Island	+	++		++				
Island	Alma Russell Island	+	++		++				
	Amphitrite Point	+	++	+	++				
	Brabant Island	+	++		++				
	Congreve Islands	+	++		++				
	Effingham Inlet	+	++		++				
	Fatty Basin	+	++		++				
	Harris Point	+	++		++				
	Hillier Island	+	++		++				
	Jacques/Jarvis Lagoon	+	++		++				
	Joes Bay	+	++		++				
	Julia Passage	+	++		++				
	Lucky Creek	+	++		++				
	Mayne Bay	+	++		++				
	Nettle Island	+	++		++				
	Pinkerton Islands	+	++		++				
	Pipestem Inlet	+	++		++				
	Ritherdon Creek	+	++		++				
	San Mateo Bay	+	++		++				
	Santa Maria Island	+	++		++				
	Snowden Island	+	++		++				
	South Stopper Island	+	++		++				
	Toquart Bay	+	++		++			++	
	Useless Inlet	+	++		++				
	Vernon Bay	+	++		++				
Strait of	Pendrell Sound	+	+		++	+			
Georgia	Talbot Cove	+	+		++	+			
	Von Donop Inlet	+	+		++	+			
	Baynes Sound	+	+	++	++	+			
	Coffin Point	+	+	++	+	+			
	Comox Harbour	+	++	++	+	+			
	Evening Cove	+	+	++	++	+			

Region	Site	Threat							
		Environmental Extremes	Non-indigenous Species	Urbanization	Marine Shellfish Aquaculture	Disease	Pulp Mill Pollution	Site-specific Alterations	Harvests
	Fanny Bay	+	+	++	++	+			
	Goldstream	+	+	++		+			
	Kulleet Bay	+	+	++	+	+			
	Kuper Island	+	+	++	+	+			
	Ladysmith Harbour	+	++	++	+	+		++	
	Nanaimo	+	+	++		+	+	++	
	Nanoose Harbour	+	+	++	+	+			
	Page Point	+	+	++	+	+			
Strait of	Ladysmith	+	+	++	+	+			
Georgia	Ship Point	+	+	++	+	+			
	Shoal Islands	+	++	++	+	+	+	++	
	Transfer Beach	+	+	++	+	+			
	Union Bay	+	+	++	+	+			
	Vesuvius Bay	+	+	++	+	+	+		
	Wall Beach	+	+	++		+			
	Baker Bay	+	+	+	+	+			
	Dacres Point	+	+	+	+	+			
	Fairview Bay	+	+	+	+	+			
	Frolander Bay	+	+	+	+	+			
	Green Bay	+	+	+	+	+			
	Harmony Islands	+	+	+	+	+			
	Jeddah Point	+	+	+	+	+			
	Jervis Inlet	+	+	+	+	+			
	Malaspina Inlet	+	+	+	+	+			
	McNaugton Point	+	+	+	+	+			
	Quarry Bay	+	+	+	+	+			
	Saint Vincent Bay	+	+	+	+	+			
	Saltery Bay	+	+	+	+	+			
	Sargeant Bay	+	+	+	+	+			
	Samuarez Point	+	+	+	+	+			
	Scardon Islands	+	+	+	+	+			
	Smuggler Cove	+	+	+	+	+			
	S. Thormanby Island	+	+	+	+	+			
	Thunder Point	+	+	+	+	+			
	Whitestone Islands	+	+	+	+	+			
	Wood Bay	+	+	+	+	+			
	Boundary Bay	+	++	++		+			
	Crescent Beach	+	++	++		+			
	White Rock	+	++	++		+			
Strait of Juan	East Chatham Island	+	+	++		?			
de Fuca	Esquimalt Harbour	+	+	++		?			
	Gorge Waterway	+	+	++		?			
	Anderson Cove	+	++	+	++	?			

Region	Site	Threat							
		Environmental Extremes	Non-indigenous Species	Urbanization	Marine Shellfish Aquaculture	Disease	Pulp Mill Pollution	Site-specific Alterations	Harvests
	Ayum Creek	+	+	+	++	?			
	Cooper Cove	+	+	+	++	?			
	Hutchinson Cove	+	+	+	++	?			
	Roche Cove	+	+	+	++	?			

Search effort

Gillespie (2009) documented published, unpublished and anecdotal information on the distribution of Olympia Oysters in B.C. Department of Fisheries and Ocean staff completed field verification of 76 historic sites in B.C. (Gillespie, unpublished data) and Norgard *et al.* (2010) documented quantitative surveys at selected sites. Olympia Oysters have been recorded from subtidal depths, thus intertidal surveys may underestimate both distribution and abundance of this species in B.C.

<u>Straits of Georgia and Juan de Fuca</u>

Olympia Oyster larvae were noted in low abundance in Pendrell Sound during Pacific Oyster studies in 1959 and 1963 (Quayle 1974) and from 1971 to 1977 (Heritage *et al.* 1976, 1977; Bourne 1978; Bourne and Heritage 1979; Heritage and Bourne 1979), and in Hotham Sound and Ladysmith Harbour in 1976–77 (Heritage *et al.* 1977; Heritage and Bourne 1979). No Olympia Oysters were reported from a survey of 147 beaches in Jervis Inlet, Hotham Sound and Sechelt Inlet by Blyth *et al.* (1997), and Kingzett *et al.* (1995c) did not record Olympia Oysters during examination of 93 sites in Okeover Inlet. Olympia Oysters can be found in Sooke Basin (Helgesen pers. comm. *in* Gillespie 1999; McNaughton pers. comm. *in* Gillespie 2009). Relatively large aggregations were reported to occur in Anderson, Roche and Hutchison coves and at Ayum Creek.

Exploratory surveys verified the presence of Olympia Oysters at 43 of 51 beaches in the Strait of Georgia surveyed in 2009 (Stanton *et al.* in prep.). Relatively high densities were recorded on beaches in Ladysmith Harbour and in artificial impoundments in Nanaimo Harbour. Olympia Oysters were consistently present on beaches in the Sunshine Coast, although densities were low and oysters were cryptic (living under rocks) in Malaspina Strait; densities were higher and oysters easier to find on beaches in Hotham Sound and Jervis Inlet. Olympia Oyster presence was confirmed from 10 of 18 beaches surveyed in the Strait of Juan de Fuca, primarily around Victoria and Sooke. Olympia Oysters were not verified from sites in Esquimalt Harbour, but high densities of Olympia Oysters were recorded over extensive areas of the Gorge Waterway and Portage Inlet. Relatively low densities were recorded at four sites in Sooke Basin, although no Olympia Oysters were found on three beaches with higher exposure to the Strait of Juan de Fuca (Whiffin Spit, Sooke Harbour and Sooke Bay).

West Coast of Vancouver Island

Olympia Oysters are locally common on the west coast of Vancouver Island. In Barkley Sound, notable sites occur in Useless Inlet, Effingham Inlet, Pipestem Inlet, Toquart Bay, Congreve Islands, Mayne Bay and Vernon Bay (Gillespie 1999, 2009; Gillespie and Bourne 2005a). Olympia Oysters also occur in at least three sites in the Broken Group Islands; they were reported from Walsh Island in the mid-1970s (Lee and Bourne 1977), Nettle Island and Jacques/Jarvis Lagoon (Gillespie 2009) and are monitored at Joes Bay on Turtle Island (Parks Canada 2008). Cross and Kingzett (1993) did not record Olympia Oysters from 118 sites examined in Clayoquot Sound, though this may be an artefact of the original objectives of the survey (determination of culture capability for clams and Pacific Oysters); Manhousat people historically harvested Olympia Oysters from Darr Island and upper Sydney Inlet (Ellis and Swan 1981). More recently, Olympia Oysters were observed at low density in Mosquito Harbour and Whitepine Cove (Gillespie *et al.* 2004; Gillespie and Bourne 2005a). In Nootka Sound/Esperanza Inlet, several beaches in Port Eliza supported large numbers of Olympia Oysters, as did beaches at Canton Creek and Nesook Bay (Kingzett *et al.* 1995a). Olympia Oysters occur in Kyuquot Sound, in Amai and Cachalot Inlets (Kingzett *et al.* 1995b). Olympia Oysters were also noted at low (or undetermined) densities near the Acous Peninsula and Bunsby Islands in Checleset Bay (Ellis and Emerson 1979; Gillespie and Bourne 2005a). Olympia Oysters were common and abundant in Klaskino Inlet (Gillespie *et al.* 2004; Gillespie and Bourne 2005a) and were a factor in establishing a provincial marine protected area in Klaskish Inlet (Ellis and Emerson 1979; Biffard pers. comm. 2009). No oysters were noted in examination of 90 sites in Quatsino Sound (Cross *et al.* 1995), nor have records been obtained through subsequent surveys (e.g., Gillespie and Bourne 2005a) or consultation with local groups. Given Elsey's (1933) reported landings of Olympia Oysters from the area, additional effort to determine whether they still exist in Quatsino is required.

Surveys in 2009 on the west coast of Vancouver Island documented presence of Olympia Oysters on 23 of 31 beaches examined (Stanton *et al.* in prep.). Olympia Oysters were common on beaches on the north and east sides of Barkley Sound (Congreve, Hillier and Santa Maria islands; Harris Point, Lucky and Ritherdon creeks; San Mateo Bay and Toquart River). They were fairly common and widespread in upper Sidney Inlet and Stewardson Inlet, present in Bacchante Bay and on one beach in Sulpher Passage, but not observed in Beddingfield Bay or at the mouth of the Megin River. They were abundant on three beaches surveyed in Port Eliza, Esperanza Inlet.

Central and North Coast

Thompson (1914) did not mention sites with Olympia Oyster from the Central or North Coast areas of British Columbia. Bourne *et al.* (1994) and Gillespie and Bourne (2005b) reported Olympia Oysters from a lagoon at the head of Watt Bay in Kildidt Sound. Bourne and Heritage (1997) reported Olympia Oysters to be common at low tide levels on two beaches in Fish Egg Inlet (one named Oyster Bay), and these sites were observed again in 2000 (Gillespie *et al.* 2004). Oysters were not noted in a survey of 127 Central Coast beaches by Peacock *et al.* (1998) or during exploratory surveys reported by Bourne and Cawdell (1992), Bourne *et al.* (1994), Heritage *et al.* (1998) and Gillespie and Bourne (2000). None were observed during examination of 190 Haida Gwaii beaches by Blyth *et al.* (1998) or during surveys of Masset Inlet and Naden Harbour by Gillespie and Bourne (1998). All of these surveys were directed at other species, and Olympia Oysters would have been recorded only incidentally. Olympia Oysters were not included in an extensive inventory of marine invertebrates of Gwaii Haanas, Haida Gwaii (Sloan *et al.* 2001).

HABITAT

Habitat requirements

Olympia Oysters are primarily found in the lower intertidal and upper subtidal zones of estuaries and saltwater lagoons (Quayle 1969, 1988), where they occur on mud-gravel tidal flats, in splash pools, near freshwater seepages, in tidal channels, bays and sounds, or attached to pilings or the undersides of floats (Couch and Hassler 1989; Harbo 1997). On the outer coast, they are found only at sheltered sites. They have been found from the intertidal zone to a depth of 50 m (Bernard 1983). They require hard substrate (i.e., rock, shell, and anthropologic substrata such as wharf structures) for successful settlement, but may settle on very small pieces (Baker 1995). The distribution of oysters varies by site; they may be in distinct beds on gravel beaches (e.g., Port Eliza), scattered at low density as single oysters (e.g., Whitepine Cove) or small clusters (e.g., Toquart River), attached to large rocks or artificial substrates (e.g., Swy-a-lana Lagoon, Nanaimo) or cryptically attached to the undersurface of large rocks (e.g., Jeddah Point).

Habitat trends

Some sites in the Strait of Georgia that historically supported large numbers of Olympia Oysters (e.g., Boundary Bay, Ladysmith Harbour, and Comox Harbour) no longer do. Habitat quality in these areas may have become degraded from urbanization, sedimentation, logging impacts (storage and bark decay), agricultural wastes, domestic and industrial pollution, mariculture and increased recreational and commercial use (traffic, boat moorage, etc.). Suitable Olympia Oyster habitat throughout B.C. has been affected by numerous human activities but impacts have not been studied or quantified.

BIOLOGY

Life cycle and reproduction

There are four major events in the reproductive cycle of *Ostrea lurida*: gonadal development, spawning, swarming, and spatting. Gonadal development commences or continues with increased water temperatures in the spring and summer. Male spawning involves release of sperm balls into the mantle cavity, and their subsequent expulsion through pumping contractions of the adductor muscles which rapidly open and close the valves. On contact with seawater, the sperm balls disintegrate, releasing spermatozoa. Female spawning occurs when eggs are extruded into the mantle cavity and fertilized by sperm which have been brought into the mantle cavity in the respiratory current. After approximately two weeks of development in the parental mantle cavity, pelagic veliger larvae are released into the water column, an event called swarming. Once the larvae have grown and are sufficiently developed, they settle and attach themselves to a hard substrate. This process is called spatting, and the newly settled oysters are referred to as spat.

Olympia Oysters are larviparous, protandrous, alternating hermaphrodites. They mature first as males and then undergo alternation of sexes between male and female throughout their life (Coe 1932b). During the male phase, hundreds of thousands of sperm balls are released, each containing approximately 2,000 sperm (Coe 1931). Self-fertilization does not occur, partly because sperm is released in packages that require exposure to seawater to dissociate into active spermatozoa (Strathman 1987) and because individuals alternate sexes and cannot be simultaneously mature as both a male and a female.

Stafford (1914) and Coe (1932b) noted retention of larvae in the parental mantle cavity until the larval shell had developed. Coe (1932b) postulated that the pelagic larval period was relatively short, limiting the potential for dispersal. Development time is temperature-dependent; Loosanof and Davis (1963) reported spatting after seven days at 24°C, 10–11 days at 21.5°C and 16 days at 18°C. Hopkins (1937) found that approximately 30–40 days were required from swarming to spatting for Olympia Oysters in Puget Sound. Brooding and pelagic larval stages were estimated to be 14–17 days each in British Columbia (Elsey 1933). Early embryos and larvae are white, but become dark grey as the larval shell develops and at the end of gestation appear as a bluish or blackish mass in the mantle chamber (Hopkins 1936). Gravid oysters were referred to as “white sick” or “black sick”, referring to the spent condition and the stage of larval development.

Total fecundity before fertilization has not been documented (Baker 1995), but Hopkins (1937) indicated that brood size for marketable oysters ranges from 250,000 to 300,000 larvae. Egg size is approximately 100–110 μm, and larval shell length is approximately 165–189 μm at swarming and approximately 300 μm at settlement (Loosanof and Davis 1963; Strathman 1987; Baker 1995).

Broods are detectable about mid-May in Puget Sound and mid-May to July in British Columbia (Stafford 1914; Hopkins 1936; Heritage and Bourne 1979). Approximately half of the adult broodstock in Puget Sound produces a second brood in the same season (Hopkins 1936).

Coe (1932a) noted that spat first appears in southern California in April and a late set usually occurred in October or November, for a spawning season of at least seven months. In Puget Sound, spatting occurs in the summer and fall, usually mid-June to late July (Hopkins 1937). In B.C., the spawning season lasts approximately three months (Stafford 1915), and spatting occurs commonly throughout July, August, and September (Elsey 1933). Hopkins (1935) showed that larvae settle preferentially on the undersides of objects.

Growth of planktonic, planktotrophic larvae is relatively rapid (Loosanof and Davis 1963; Strathman 1987). Larvae are released into the water column at shell diameters of approximately 165–189 µm and settle in 2–3 weeks at a length of approximately 300 µm. After settlement, Olympia Oysters grow relatively slowly, requiring 4–5 years to reach a marketable size of approximately 50 mm in diameter (Sherwood 1931). Three to four years are required to reach shell diameters of 35–45 mm in Washington (Couch and Hassler 1989) and little growth occurs thereafter (Baker 1995).

Olympia Oysters require an ambient water temperature of at least 12.5°C to reproduce (Hopkins 1937), but reproduction occurs more commonly at temperatures of 14–16°C (Strathman 1987). Temperature is a critical element in the timing of reproductive phases; periods of low temperature can interrupt the alteration of sexes, which resumes when temperatures increase (Baker 1995). Although oysters may mature in their first year and more than one generation might be produced in a favourable season in southern California (Coe 1932b), oysters subjected to cooler temperatures farther north may result in only one or two spawnings in midsummer (Couch and Hassler 1989), mature later, and are generally less productive.

Age at first reproduction is dependent upon the time of settlement in the summer (Coe 1932b). Given appropriately warm temperatures, the first male phase is complete, ovarian follicles form and the first ova are ready for liberation approximately 22–30 weeks after settlement. The ensuing female stage lasts several weeks, encompassing two periods of ovulation and liberation of eggs. The following male phase occurs 8–12 days later, coincident with the release of developed larvae. Therefore, under appropriate temperature regimes, as many as three sexual phases might occur in the first year of life of individuals that were spawned in early spring (one male and female phase in the fall and a second male phase in the spring). Male and female phases alternate, presumably for the remaining life span of the individual. Because of lower temperatures and later settlement in British Columbia, first male sexual maturity is not usually achieved until the second breeding season, i.e., at nearly one year of age (Elsey 1933).

As with most bivalve molluscs, mortality is generally highest in planktonic larvae and in early post-larval stages after settlement. Mortality rates generally decrease as surviving oysters grow into size refuges from most forms of predation. Most mortality in adults is caused by either disease, exposure to environmental conditions that exceed physiological tolerances, or pollution (Quayle 1969, 1988).

The maximum age of Olympia Oysters is unknown. McKernan *et al.* (1949) recorded approximately 34% annual mortality in adult control groups held for long-term bioassays. Baker (1995) examined fossil Olympia Oysters from Coos Bay, Oregon, that exhibited at least 10 major hinge annuli, which may represent age in years. As no information is available regarding either maximum age or age distribution of Canadian oysters, generation time (defined as average age of parents in the population) is unknown, but may approach 10 years.

Olympia Oysters are obligate filter feeders. Their larvae are planktotrophic; they swim actively and feed on organic material in the water column. Adults rely on suspended organic materials and planktonic organisms. Diatoms and dinoflagellates are preferred food items, and other food types include detritus from disintegrating marine plant and animal matter, bacteria, minute flagellates, other protozoa, and gametes of marine algae or invertebrates (Barrett 1963).

Physiology and adaptability

Oysters do not exhibit specific behaviours other than selection of a settlement site. From that point, the physical protection of their shells and their physiological tolerances (see **Environmental extremes**) determine their ability to survive. They cannot move away from predators or migrate to areas which offer more suitable temperatures, water quality or food supply.

Early culture of Olympia Oysters and recent rehabilitation efforts were all predicated on creating or improving habitat that promoted settlement of juveniles in appropriate conditions to increase survival. Dykes or impoundments were used in culture and the placement of appropriate settlement substrates low in the intertidal zone is key to rehabilitation. The presence of Olympia Oysters in the artificial Swy-a-lana Lagoon in Nanaimo demonstrates successful (if unintentional) development of suitable site for Olympia Oysters through provision of standing water low in the intertidal zone.

Dispersal and migration

Olympia Oysters are a classic example of a metapopulation (Hanski and Gilpin 1991). Olympia Oysters are motile only during a short planktonic larval period. Adults are sessile regardless of whether individuals are attached to the substrate or lying on it, and thus Coe (1932b) suggested that opportunities for dispersal are limited by the short larval stage. Baker (1995) suggested that Olympia Oyster larvae stay relatively close to the sites where they were spawned, citing their rarity in near-shore coastal plankton and some large-scale distributional considerations.

Baker (1995) found that larval dispersal in Olympia Oysters is limited and that little genetic exchange occurs between coastal sites in Washington, Oregon, and northern California. As an example, he cited the prehistoric extinction of Olympia Oysters in Coos Bay, Oregon, with recolonization occurring only in recent times. The time required to re-establish sites may be a function of lack of larval transport from other sites, as well as improvement of Olympia Oyster habitat by dredging activities (Baker pers. comm. *in* Gillespie 2009).

Quayle (1969) reported transport of Pacific Oyster larvae over a distance of 56 km from breeding stock in Ladysmith Harbour in the 1930s. Given that in British Columbia the larval period of Olympia Oysters is similar to that of Pacific Oysters (2–3 weeks, depending on temperature), dispersal of at least 56 km can be expected. Studies on dispersal of Olympia Oysters have not been carried out in B.C. The limiting factor for successful dispersal is likely availability of suitable habitat, which is less common in steep-sided fjord and inlet complexes that comprise much of B.C.'s coastal geography.

Interspecific interactions

Predation

Olympia Oysters are preyed upon by crabs, gastropods, sea stars, and birds. Quayle (1969, 1988) indicated that three species of crabs (Dungeness Crab, *Cancer magister*; Red Rock Crab, *C. productus*; and Slender Crab, *C. gracilis*) have some minor predatory effects on oysters in British Columbia. All three species can prey on adult Olympia Oysters, and the Shore Crab (*Hemigrapsus oregonensis*) is thought to prey on juveniles. Red Rock Crabs are specifically mentioned as oyster predators in Oregon (Robinson 1997) and California (Barrett 1963).

Four species of sea stars are specifically identified as oyster predators (Quayle 1969, 1988): the Ochre Star (*Pisaster ochraceus*), Pink Star (*Pisaster brevispinus*), Mottled Star (*Evasterias troschelii*), and Sun Star (*Pycnopodia helianthoides*). Sea stars are not major predators in the upper intertidal zone due to their limited tolerance of desiccation, and they are intolerant of the lower salinity in oyster dikes (Sherwood 1931).

Predatory gastropods can cause significant mortality in oysters. Elsey (1934) stated that “serious inroads are now being made on the native oyster by an oyster-drill imported from the Atlantic coast”. The gastropod was undoubtedly the Atlantic Oyster Drill, *Urosalpinx cinerea*, which was introduced to Boundary Bay and Ladysmith Harbour with Atlantic Oysters (Carl and Guiguet 1957; Quayle 1964) but has since disappeared from these sites (Gillespie 2007). Another introduced gastropod, the Japanese Rocksnail, *Ocinebrellus inornatus* (=*Ceratostoma inornatum)*, is a serious predator of Olympia Oysters (Hopkins 1937; Chapman and Banner 1949). *Ocinebrellus inornatus* is present in British Columbia, though its distribution is relatively limited and dispersal is nearly negligible because of the lack of a pelagic larval stage and patchiness of available habitat (Carl and Guiguet 1957; Quayle 1964, 1969, 1988). Spread of these introduced predators was also curtailed by regulations prohibiting movement of oysters from areas suffering predation to other areas. The native Frilled Dogwinkle, *Nucella lamellosa*, is known to prey on both adult Olympia Oysters and spat, but prefers mussels to oysters (Hopkins 1937). A moon snail, *Euspira lewisii*, does occasionally prey on adult Olympia Oysters, but is not able to penetrate dense oyster beds due to its large soft body and semi-burrowing locomotion (Baker 1995).

White-winged Scoters (*Melanitta fusca*), Black Scoters (*M. nigra*), and Greater Scaup (*Aythya marila*) have been identified as predators of Olympia Oysters (Baker 1995). Anomuran shrimps (*Upogebia pugettensis* and *Neotrypaea californiana*) can cause direct mortality by smothering oysters during their burrowing activities, and caused oyster dikes to drain, leading to increased mortality from temperature extremes (Baker 1995).

Parasitism

Meyer *et al.* (2010) reported five parasitic or symbiotic organisms from Olympia Oysters collected at five B.C. sites. These included *Rickettsia*-like prokaryotes, *Mytilicola* sp., *Rhyncodida*-like ciliates, encapsulated copepods, and an unknown protist. Most were at low levels of prevalence and intensity.

The introduced Japanese Oyster Leech (actually a flatworm), *Pseudostylochus ostreophagus*, has become established in Puget Sound and “assumes pest proportions” in some years (Quayle 1988). It has been accused of causing large mortalities in Olympia Oyster spat in Puget Sound (Woelke 1956). It is well established in southern British Columbia and has caused significant mortality in juvenile Pacific Oysters and Japanese Scallops, *Mizuhopecten yessoensis* (Bower and Meyer 1994).

Olympia Oysters are susceptible to infection by a parasitic copepod, *Mytilicola orientalis*, which lives in the lower intestinal tract of bivalve molluscs (Bernard 1968, 1969; Bradley and Siebert 1978). Although some early reports indicated that infestation led to reduced condition, little evidence of this was found in Bernard’s studies. Infection appears to cause no pathological effects (Bower *et al.* 1994). In all studies, infestation rates were higher in associated mussels (*Mytilus* spp.) than in Olympia Oysters.

Olympia oysters are host to Pea Crabs (*Pinnixia littoralis*) with no direct pathology reported (Bower *et al.* 1994).

Disease

Large-scale mortality of Olympia Oysters from systemic infection by the flagellate *Hexamita* sp. was reported in Puget Sound (Stein *et al.* 1959). Low levels of these flagellates are commonly found in the intestinal tract of oysters with no pathological effects (Bower *et al.* 1994). However, pathogenic outbreaks of this disease resulted in up to 75% mortality in two months. Neoplastic disorders and haplosporidian infections have been reported in Olympia Oysters from Alsea and Yaquina Bays (Mix 1975; Mix and Sprague 1974), and Friedman *et al.* (2005) reported infection of Olympia Oysters in San Francisco Bay by a *Mikrocytos*-like protest, a haplosporidian and haemic neoplasia.

Meyer *et al.* (2010) surveyed Olympia Oysters from five B.C. sites for evidence of pathology using histological and polymerase chain reaction (PCR) assays. They detected six pathologies of unknown etiology including hemocytic neoplasia, basophilic inclusions in the digestive gland epithelium, metaplasia of digestive gland tubules, diapedesis, and diffuse and focal hemocyte infiltration. None were believed to have an effect on Olympia Oysters at the individual or site level. PCR assays were conducted for known bivalve pathogens, including *Mikocytos mackini*, *Haplosporidium* spp., and *Bonamia* spp.; none were detected.

Olympia Oysters are susceptible to Denman Island disease caused by the intracellular parasite *Mikrocytos mackini*. The disease is known only from the Georgia Strait and other specific sites on Vancouver Island (Bower *et al.* 1994). The disease causes mortality of larger oysters at low tide levels in the spring, following a 3–4 month period of temperatures less than 10°C. It is associated primarily with Pacific Oysters, but Olympia Oysters may be more susceptible to both infection and the resulting disease (Bower *et al.* 1997; Carnegie *et al.* 2003). Bower *et al.* (1997) speculated that the arrival of the disease with imported Pacific Oyster seed in the 1930s could have been responsible for drastic reductions in Olympia Oyster numbers in British Columbia, but noted that the disease was yet to be reported from Japan. Friedman *et al.* (2005) characterized Denman Island disease as a potential threat to recovery of Olympia Oyster numbers.

Competition

Barret (1963) found that under temperature regimes that allow spawning of *Crassostrea*, Olympia Oysters would suffer competitive disadvantage both through total fecundity (which is higher in Pacific and Atlantic oysters) and because the larval period for Olympia Oysters is longer, exposing them to the hazards of pelagic existence for longer periods than their introduced competitors. However, the temperature requirement for successful spawning is lower for Olympia Oysters (12.5–14°C) than for Pacific Oysters (20–23°C), and the larval periods in British Columbia are of similar duration, 18–30 days depending on temperature (Quayle 1988). Therefore, Olympia Oysters (particularly in protected waters) can spawn successfully in most years, whereas Pacific Oysters only spawn in warmer water areas (e.g., Pendrell Sound) and only in years with unusually warm temperatures. Because half of the larval development occurs within the protection of the parental mantle cavity, it seems unlikely that Pacific Oysters have a competitive advantage over Olympia Oysters in this context.

The gill ostia (the passages through which water passes to the branchial chamber) also need to be large enough to allow eggs to pass from the gonad. The larger size of the eggs of Olympia Oysters require larger ostia (Elsey 1935), which, in turn, decrease the feeding efficiency of Olympia Oysters for smaller particles. Thus, oysters of the genus *Crassostrea*, which have smaller eggs and smaller ostia, may have a competitive advantage over Olympia Oysters, because they can take advantage of smaller particles (nannoplankton) when feeding (Elsey 1935; Barrett 1963; Couch and Hassler 1989).

POPULATION SIZES AND TRENDS

Sampling effort and methods

Until recently, few quantitative data were available for Olympia Oysters in British Columbia. Gillespie (2009) summarized density estimates and biological information from surveys on the west coast of Vancouver Island between 2000 and 2004 (Gillespie *et al.* 2004; Gillespie and Bourne 2005a; unpublished data; Table 3). Relatively few sites were surveyed, and methods used were non-standardized. Recent investigations have verified historical reports of Olympia Oysters in qualitative (presence/absence) and directed abundance surveys (Norgard *et al.* 2010; Stanton *et al.* in prep.). Presence/absence verifications used visual search methods while abundance surveys used various designs and sampling intensities (see Norgard *et al.* 2010 for documentation).

Table 3. Quantitative abundance estimates of Olympia Oysters in British Columbia, Canada. Table 3A is density estimates (oysters m^{-2} and dead shells m^{-2}) from exploratory surveys (Gillespie and Bourne 2005a, unpublished data), Table 3B is density estimates (oysters m^{-2}) and total abundance estimates (oysters) from areas surveyed in 2009 (Norgard *et al.* 2010).

A)

Site	Date	N	Live oysters		Dead shells	
			Mean (±95%CI)	Range	Mean (±95%CI)	Range
Amai Inlet	2002/07/10	27	353 (±94)	0–891	155 (±45)	0–530
Klaskino Inlet	2002/07/07	76	109 (±35)	0–866	14 (±5)	0–144
Klaskino Inlet	2007/06/28	59	240 (±53)	0–770	48 (±25)	0–722
Port Eliza	2002/07/11	54	360 (±76)	0–1,203	281 (±78)	0–1,348

B)

Site	Area (m^2)	Density			Abundance		
		Mean	Lower 95% CI	Upper 95% CI	Total	Lower 95% CI	Upper 95% CI
Harris Point	960	85.3	43.8	126.8	81,920	42,070	121,770
Ladysmith Harbour	6,750	26.1	19.1	33.1	176,138	128,857	223,419
Gorge Waterway	250	153.9	119.4	188.3	38,467	29,855	47,078
Baker Bay	550	385.3	228.9	541.8	211,933	125,888	297,978
Swy-a-lana Lagoon	880	6.99	5.1	8.9	6,148	4,444	7,852
Port Eliza 2	2,525	199.5	151.8	247.1	503,653	383,300	624,006
Port Eliza 3	9,920	213.5	136.0	291.0	2,117,639	1,348,631	2,886,631

All of the estimates represent baseline surveys, primarily to test potential survey protocols. A few sites have multiple surveys, but are only a year apart and often do not utilize standard methodologies, therefore, they are not informative for population trends.

Abundance

Quantitative population estimates (both historic and recent) of Olympia Oysters are rare and time series to examine trends in abundance do not exist (Table 3). Although there is some anecdotal information describing sites that supported large enough numbers of Olympia Oysters to attract commercial fisheries, until recently little attention has been directed at Olympia Oyster abundance in British Columbia. Estimates of total abundance from surveys in 2009 varied widely; some sites supported few scattered individuals while on other beaches tens or hundreds of thousands were estimated and, in one instance in Port Eliza, there were over two million individuals in one bed.

Qualitative information regarding historic abundance trends exist in the literature. Large-scale Olympia Oyster culture occurred at Crescent (part of the City of Surrey) in Boundary Bay from the early 1900s through the 1930s (Stafford 1917; Sherwood 1931). Low dikes were constructed of concrete or creosoted timbers to provide standing water which protected the oysters from temperature extremes at low tide (Sherwood also mentions that dike culture was not practised at Ladysmith, implying that no other site in British Columbia used dikes). Substrates were altered by adding gravel or shells to allow easier access by workers and prevent smothering the oysters in silt and mud. The beds were "seeded" by placing shell and other cultch material (materials that provided suitable surfaces to promote settlement of spat) in the diked areas to collect natural sets. The oysters were allowed to grow in the diked areas for several years and were harvested when large enough for market; areas were harvested on a rotational basis, not annually.

The greater density of Olympia Oysters in Boundary Bay may have been established and maintained primarily through the efforts of culturists (Stafford 1916), and the combination of significant losses from cold winter temperatures in 1940 and the shift in market preference to Pacific Oysters led to the cessation of culture efforts there. Quayle (1988) indicated that only occasional specimens could now be found there. Recent investigation produced few scattered occurrences, mixed with abundant Pacific Oysters (Stanton *et al.* in prep.).

Anecdotal information (from both the literature and personal communications) indicates that current abundance of Olympia Oysters in the Strait of Georgia is low compared to historic levels (Gillespie 1999, 2009). It is generally believed that declines in numbers of individuals occurred between the late 1800s and 1930. The decline was manifested mostly by the disappearance of large oyster aggregations in specific sites, particularly Boundary Bay and Ladysmith Harbour.

Numbers of oysters in Ladysmith Harbour, Nanoose Bay and Comox Harbour are greatly reduced from earlier descriptions. Stafford (1913b) stated that Olympia Oysters were not common in Departure or Hammond bays, but in Nanoose Bay and Oyster [Ladysmith] Harbour, they occurred "by the thousands, free on the surface, and more or less spotted with barnacles". Elsey (1933) indicated that the oyster beds of Ladysmith Harbour were seriously depleted, and that the number of oysters in the beds once contained likely at least ten times the then-current numbers, which was estimated at "not more than five or six thousand bushels". He also indicated that other beds that were fished (Toquart and Blunden Harbours; Fish Egg, Esperanza and Quatsino Inlets; and the Bardswell Group) produced almost exclusively old oysters. This indicated to him that the beds had been "very slowly built up" and that intensive fishing would quickly deplete them.

Olympia Oysters were recently found in Ladysmith Harbour at low densities, and exhibited relatively high densities at one site below a commercial oyster plant (Polson and Zacherl 2009; Stanton *et al.* in prep.; Table 3). Norgard *et al.* (2010) estimated abundance at this site to be approximately 176,000 oysters. An examination of Nanoose

Bay yielded only one Olympia Oyster, despite significant search effort and consultation with local oyster culturists (Stanton *et al.* in prep.). Olympia Oysters were present at low densities in Baynes Sound, but extremely rare (two individuals observed) in Comox Harbour (Stanton *et al.* in prep.). Swy-a-lana Lagoon in Nanaimo (Norgard *et al.* 2010) was surveyed; total abundance was estimated at approximately 6,000 oysters.

Olympia Oysters were widespread and common on the mainland shore of the Strait of Georgia (Stanton *et al.* in prep.). Olympia Oysters were present at relatively low densities and in cryptic habitat (mainly under rocks) in Malaspina Strait, while they were present a higher densities and easier to observe in Hotham Sound and Jervis Inlet. Norgard *et al.* (2010) estimated the number of individuals in Baker Bay to be more than 200,000 individuals (Table 3).

In the Strait of Juan de Fuca, Olympia Oysters are known from the Gorge Waterway and Portage Inlet in Victoria and Sooke Basin (Stanton *et al.* in prep.). Norgard *et al.* (2010) estimated abundance at one site in the Gorge Waterway to be approximately 38,000 oysters. This survey only examined a small portion of the site; Olympia Oysters were present at 28 of 31 transects examined in the Gorge Waterway and Portage Inlet, but oysters also exist as extensive subtidal reefs (Gillespie, unpublished data).

Olympia Oysters have been reported from many sites on the west coast of Vancouver Island (Table 1); this list is certainly incomplete. The highest reported abundances also occurred in west coast Vancouver Island; a small bed at Harris Point in Barkley Sound was estimated to hold over 81,000 oysters and two sites in Port Eliza were estimated to support 500,00 and over 2,000,000 oysters (Norgard *et al.* 2010; Table 3).

In summary, there have been major declines in populations during a period of fisheries exploitation between the late 1800s and 1930. The decline was primarily due to depletion of large concentrations from specific sites. Small populations with low densities still exist in the Strait of Georgia; on the west coast of Vancouver Island, oysters are locally common and abundant at more sites.

Fluctuations and trends

There currently are few data on population trends. Historic information on Olympia Oyster population fluctuations indicate these are primarily in the form of catastrophic mortality (environmental or anthropogenic) usually not followed by slow recovery. In the absence of other information, the persistence of Olympia Oyster populations 70 years or more after significant fisheries have taken place may indicate that populations are relatively stable at current low levels of abundance. Whether abundance remains limited in the Strait of Georgia by habitat alteration, pollution, disease or other causes is unknown. Aggregations of Olympia Oysters on the west coast of Vancouver Island may reflect lesser threats to habitat or health of oysters in relatively undeveloped areas. Aggregations north of Vancouver Island likely represent the northern limit of distribution for the species; response of these aggregations to anthropogenic or large-scale (oceanographic or climatic) changes cannot be predicted at this time.

The management plan for Olympia Oysters (DFO 2009) recommends identification and protection of index sites to monitor fluctuations and/or trends in abundance of Olympia Oysters. This requires development of standardized survey protocols which can be utilized by collaborators in Olympia Oyster conservation (federal and provincial governments, First Nations, fisheries and aquaculture industries, academic institutions, community stewardship groups, etc.). These protocols are currently being developed and tested (Norgard *et al.* 2010).

Rescue effect

Populations of Olympia Oyster exist in Washington, Oregon, California, and Mexico. Immigration is possible only from the closest sites (Puget Sound and possibly Willapa Bay or Grays Harbor) because of larval dispersal periods and patterns (see **BIOLOGY: Dispersal and migration**). The oysters in Puget Sound are likely best adapted to conditions in the Strait of Georgia; those from outer coastal Washington may be well adapted to conditions on the west coast of Vancouver Island.

The results of molecular analyses by Polson *et al.* (2009) indicate that there are measurable genetic differences between Olympia Oysters from Washington and British Columbia, leading them to suggest that Canadian populations may have arisen as glacial relicts (see **Population spatial structure and variability**). This dissimilarity decreases the attractiveness of Washington populations as sources for re-establishment of potentially locally extirpated sites in Canada. The sample size is small (only two sites in British Columbia and one in Washington) and the clustering of sites from the Strait of Georgia and Barkley Sound, distinct from southern sites, is not intuitive; one might expect greater differences between inside waters (Strait of Georgia and Puget Sound) and outer coastal waters (west coast of Vancouver Island and Willapa Bay/Grays Harbor) than on a north-south boundary. Molecular analyses sampling more sites may reveal other patterns than the preliminary analysis.

THREATS AND LIMITING FACTORS

Historic commercial fisheries

The historical decline in the Olympic Oyster was largely due to excessive, unsustainable harvests (see below). While these harvests are now controlled, anecdotal information suggests that numbers of individuals were reduced to levels that would have required decades or longer to recover and would have left them more susceptible to other threats. While overharvest cannot be considered ongoing in and of itself, the after-effects persist; historically, beds in many locations were decimated. Once they reached this state they became even more vulnerable to other threats such as temperature extremes, particularly given biological traits. They are also more vulnerable to local extirpations associated with various types of stochasticity.

Galtsoff (1929) understood the sensitivity of large beach and reef aggregations of Olympia Oysters to human impacts, such as fisheries:

> The apparent richness of the natural reef is often misleading because it represents the accumulation of an oyster population that lived undisturbed for a period of possibly several hundred years. Because of the low temperature of northern waters, spawning and setting occur only in exceptionally warm years so that the stock is not replenished regularly. With the beginning of fishing operations, the number of adult oysters on such bottoms quickly diminishes, thus decreasing the chance for good setting, and in a few years the whole population of a reef can be wiped out.

The overall history of Olympia Oyster exploitation on the west coast was one of overharvest and eventual replacement with larger, more marketable species. Commercial production from Olympia Oyster beds required harvests of huge numbers of animals; approximately 1,600 Olympia Oysters are required to produce a gallon of meats (compared to 150–250 Atlantic Oysters or 50–200 Pacific Oysters; Hopkins 1937).

A small commercial fishery for Olympia Oysters began in California in approximately 1840. The fishery was unable to meet local market demand, and Olympia Oysters were imported from Willapa Bay, Washington, beginning in the 1850s (Atlantic Oysters were imported to San Francisco Bay beginning about 1870). Townsend (1893) complained of heavy Olympia Oyster spatfall crowding and overgrowing the Atlantic Oysters that were the preferred market species. He stated that the species grew “twice as large at Willapa Bay, Washington, as it does at San Francisco”. Olympia Oysters were only used for “the making of garden walks” or “ground up and scattered about poultry ranches”. Natural beds in Elkhorn Slough, Humboldt, Tomales and Newport Bays were depleted in the early 1900s. Olympia Oyster stocks continued to decline after the introduction of Pacific Oysters in the 1920s and 1930s. Failure of the fishery was attributed to a number of factors, including limited financial resources, lack of experience raising oysters, poor spat collection, five years of growth required to reach market size, small meat yield, and a limited winter market season.

Commercial fisheries for Olympia Oysters began in Yaquina Bay, Oregon, as early as 1854 (Robinson 1997). By 1899, commercial production had fallen below 60 t, and the oyster industry shifted to imported Atlantic Oysters. The Oregon oyster industry was generally unproductive until the importation of Pacific Oysters in the 1930s and is now entirely dependent on cultured Pacific Oysters.

Harvests of natural beds at Willapa Bay, Washington, began in 1850, then dwindled, and were essentially finished by 1915 (Galtsoff 1929; Sherwood 1931). Naturally occurring beds had been largely depleted by the 1870s, and the fishery was supported into the early 1900s by enhancement and cultivation (Steele 1957; Lindsay and Simons 1997). Galtsoff (1929) related newspaper reports from the late 1800s that may have indicated unusually high natural mortalities in Willapa Bay in 1867–68, which may have contributed to declines in numbers. Hopkins (1937) indicated that Olympia Oyster beds in Willapa Bay had been completely destroyed, and that Olympia Oysters were difficult to find, even in local markets.

Production from Puget Sound was more consistent, primarily because greater progress was made in developing dike culture methods (Steele 1957; Lindsay and Simons 1997). Production suffered after 1928 when a pulp mill was opened in Shelton and discharged sulphite waste liquor into Oakland Bay. By the time the mill closed, which resulted in improved water quality and increased oyster growth, survival and recruitment, most oyster growers had switched to Pacific Oyster culture.

Commercial landings of Olympia Oysters in British Columbia began approximately in 1884 and continued to about 1930. The fishery was small, and annual landings probably never exceeded 300 t (Bourne 1997). The fishery declined due to overfishing (Stafford [1913a] was already warning of the demise of the oyster fishery and of oyster numbers in B.C.) and severely cold winters which caused extensive mortalities. A severe winter in 1929 destroyed many of the Olympia Oysters in Ladysmith Harbour, and another severe frost in about 1940 destroyed most of the remaining oysters in Boundary Bay (Quayle 1969). Elsey (1933) indicated that increased landings of oysters (primarily Olympia Oysters) between 1925 and 1930 was the result of increased effort expended in thinly stocked and isolated areas and in harvesting undersized or inferior oysters.

Sherwood (1931) stated that natural oyster beds on the Pacific coast had been exhausted by 1930 and that the oyster industry was essentially confined to Puget Sound. Production from British Columbia and Oregon was considered insignificant, and the entire Pacific production was less than 1% of the U.S. total.

Harvest is now a negligible threat, managed through regulation (see **PROTECTION, STATUS AND RANKS**), although the effectiveness of these regulations cannot be assessed. It is believed to be a low risk throughout the species' range in British Columbia (Table 2). However, there is still concern that some Olympia Oysters are still being taken as bycatch with the Pacific Oyster.

Environmental extremes

Olympia Oysters cannot withstand freezing at low tide. Significant mortalities have been attributed to unusually cold weather, including the final depletion (to commercially insignificant levels after a history of overfishing) of oysters in Ladysmith Harbour in 1929 and Boundary Bay in approximately 1940 (Quayle 1969). Edmondson (1923) attributed an increase in the price for Yaquina Bay oysters in 1917 to increased market demand due to decreased production after "partial destruction of the beds of the Puget Sound region by freezing during a previous season [1915]". High summer temperatures can also cause considerable mortality in young-of-the-year oysters.

The vulnerability of Olympia Oysters to freezing or high summer temperatures likely explains the limitation of large aggregations to low tidal levels, lagoons, or other habitats with standing water which serves to insulate the oysters from temperature extremes. Physiological temperature requirements for gonadal development and successful spatting likely explain why there are few large aggregations of Olympia Oysters reported from northern British Columbia.

Small relict numbers of Olympia Oysters survive at low tidal levels which are rarely exposed to freezing air temperatures and in instances where oysters have attached to the undersides of floating structures which are constantly submerged.

Extreme temperatures (particularly winter lows) are broadly clinal from south to north. It is believed that Olympia Oysters at northern sites would be more affected by extreme temperatures than those at sites in the Strait of Georgia and on the west coast of Vancouver Island (Table 2). As intertidal individuals can be eliminated by freezing, the impact would be serious. Recruitment failure in the intertidal zone can occur due to high summer temperatures. Extreme temperature events could increase in frequency and intensity in the future, possibly within ten years or three generations.

Non-indigenous predators and competitors

Olympia Oysters support a significant suite of native predators including crabs, gastropods, sea stars and birds (see **Interspecific interactions**). Additional predation by non-indigenous gastropods and flatworms has been speculated to reduce recovery potential for Olympia Oysters in the U.S. (Buhle and Ruesink 2009). These predators occupy relatively small areas in British Columbia and guidelines are in place to ensure that introduced predatory gastropods are not transported to new sites.

Of more immediate concern is the recent establishment of the European Green Crab, *Carcinus maenas*, on the west coast of Vancouver Island (Gillespie *et al.* 2007; Behrens Yamada and Gillespie 2008). The Green Crab is a notoriously invasive species that has demonstrated significant impacts on clams, mussels, juvenile flatfish, crabs and other species (Cohen *et al.* 1995 Grosholz and Ruiz 1995; Grosholz *et al.* 2000; Jamieson *et al.* 1998; McDonald *et al.* 2001; Taylor 2005). In the laboratory, Green Crabs have demonstrated preference for Olympia Oysters over other bivalves (Palacios and Ferraro 2003). Green Crabs are present (and often abundant) on beaches throughout the west coast of Vancouver Island (Gillespie *et al.* 2007), which also support significant numbers of Olympia Oysters. There is no information for Canada regarding the impact of Green Crab predation on abundance of Olympia Oysters.

Trimble *et al.* (2009) documented competition for space between post-settlement Olympia Oysters and fouling organisms (ascidians, sponges and hydrozoans). Naturally settling competitors, mostly non-indigenous, reduced oyster survival by 50% and growth by 20%. Five species of introduced ascidians have been reported from B.C. waters (*Styela clava*, *Ciona intestinalis*, *Botryllus schlosseri*, *Botrylloides violaceus* and *Didemnum* sp.) (Herborg and Therriault 2007). The distribution of *Ciona* is not well documented; the remaining four species are found in the Strait of Georgia and two on the west coast of Vancouver Island (*Botryllus and Didemnum*) and one throughout B.C. waters (*Botrylloides*). Habitat suitability modeling indicated that *Styela* and *Botrylloides* could spread throughout B.C. waters while the potential distribution of the other species was limited.

Primary non-indigenous predators of Olympia oysters are exotic predatory gastropods and European Green Crab. Moderate risk is assigned to sites known to harbour either Green Crabs or Japanese Oyster Drills and higher risk is assigned to one site that harboured both (Table 2). Habitat suitability models predicted that Green Crab could spread throughout British Columbia should larval transport or human transplant carry them beyond the west coast of Vancouver Island (Therriault and Herborg 2008).

Human alteration of habitat

Suitable estuarine habitats are limited in British Columbia, and many estuaries have been adversely affected by human practices hat have resulted in the loss of some estuaries and salt lagoons. Pollutants and other wastes may be detrimental to oyster numbers, as is increased siltation resulting from changes in forest or land management practices. Estuaries and bays that previously supported Olympia Oysters (e.g., Ladysmith Harbour and Boundary Bay) are now heavily affected by urbanization, pollution and other impacts of commercial and recreational use.

Human alteration of habitat by pollution or disruption of the habitat itself are either broad-scale (urbanization, domestic pollution) or site-specific (log storage, dredging, filling, sedimentation). Many sites in the Strait of Georgia (Table 2) are likely adversely impacted now by urbanization and domestic pollution and will likely continue to be in the future. Site-specific threats were more difficult to categorize (Table 2). Dredging occurs only occasionally for port development or for shipping berth renovation, and does not occur annually outside of Fraser River Main Arm near Stevenston and in the North Arm. Log dumps and log storage areas are found throughout the Canadian range of Olympia Oysters but the effects are restricted to the immediate area. Extreme or catastrophic sedimentation from landslides or flooding brought about by changes in land use patterns (e.g. logging, agriculture, etc.) can bury Olympia Oyster populations.

Disease

Some members of the U.S. oyster industry believe that disease played a large role in the collapse of some stocks of Olympia Oysters (Bourne pers. comm. *in* Gillespie 2009), and Bower *et al.* (1997) speculated that the possible introduction of Denman Island disease with imported Pacific Oysters could have caused declines in Olympia Oysters. However, there is no direct proof that this, or any other disease, is a cause of historic reductions in abundance.

Denman Island disease is endemic to the Strait of Georgia, south to Puget Sound, and two sites on west coast of Vancouver Island that never harboured Olympia Oysters (Lemmens Inlet and Nuchatlitz Island—Bower *et al.* 1994; Meyer pers. comm. 2010). All sites within the Strait of Georgia, including Boundary Bay sites, could be susceptible to this pathogen; the Victoria/Sooke sites are more questionable (Table 2). The severity of this threat may be low, and its scope may be limited, because the distribution of Denman Island disease appears tied to the range of Pacific Oysters, the primary host (although Olympia Oysters are susceptible). The origin of *Mikrocytos mackini*, the organism responsible for Denman Island disease, is not clear; it is suspected to be from the western Pacific but has not been detected there.

Pollution

There is considerable literature documenting the deleterious effects of sulphite waste liquor, released from pulp mills, on Olympia Oysters (e.g., Hopkins *et al.* 1935; McKernan *et al.* 1949; Odlaug 1949; Steele 1957). Exposure to sulphite waste liquor in the laboratory induced lack of growth, decreased condition/meat yield, failure to reproduce, and high mortality rates.

The local extirpation of Olympia Oysters in Oakland Bay and Budd Inlet, Puget Sound, as well as a general decline in numbers of individuals between 1926 and 1945 throughout southern Puget Sound, was linked to waste from pulp mills (McKernan *et al*. 1949, Steele 1957). There is clear evidence that sulphite waste liquor from pulp mills in Puget Sound had a significant adverse effect on Olympia Oyster abundance there. It is possible that similar effects occurred in British Columbia, but there are no data on the impacts of pulp mill effluent on Olympia Oysters in B.C.

The anti-fouling compound tributyltin (TBT) has been implicated in failures of the closely related European Flat Oyster (*Ostrea edulis*) to grow or spawn in France (Thain and Waldock 1986). Anti-fouling paint is common on vessels, and numerous estuarine habitats (e.g., Ladysmith Harbour, Comox Harbour, Nanoose Bay) support marinas and moorages for many vessels. Bright and Ellis (1990) demonstrated a high incidence of imposex (development in the female snail of a penis and pallial vas deferens, causing sterility in some species) in three species of gastropods (*Nucella canaliculata*, *N. lamellosa,* and *N. ostrina* [reported as *N. emarginata*]) in southern British Columbia, a result of exposure to TBT. Their data suggest that water-borne concentrations of TBT were high enough to induce imposex in nearly all female snails examined in Georgia Strait and the Straits of Juan de Fuca. Incidence of imposex was less severe and more localized on the west coast of Vancouver Island and in the Central and North Coasts. Although chambering (abnormal shell growth characterized by large empty chambers in the shell matrix) of Pacific Oysters has been demonstrated in British Columbia, there is no published research examining the effects of TBT on *O. lurida*.

Canada prohibited the use of TBT-based paints on small vessels (<25 m length) in 1989, but TBT is still leaching from the hulls of larger Canadian and international ocean-going vessels (Thompson 1996). Although it is possible that TBT could have an impact on Olympia Oysters (Thompson pers. comm. *in* Gillespie 1999), and the spatial correlation of reduced numbers of Olympia Oysters and observed TBT-related effects in other species is compelling, there has been no research that demonstrates a detrimental effect of TBT on Olympia Oysters. Although anti-fouling compounds would not have contributed to declines in Olympia Oysters in the early 1900s, they may have served more recently as an additional stressor preventing recovery.

The level of threat currently posed by pulp mill effluent is difficult to assess because effluent treatment practices have changed since mortalities were reported in the 1940s. The Kraft process is sulphate-based and is currently the dominant pulping process; sulphite-based pulp, which employs calcium or magnesium sulphite, now accounts for less than 10% of chemical pulping processes. There are coastal mills that employ Kraft processes in Howe Sound, Crofton, Nanaimo, Powell River and Campbell River. Gold River has been closed for a decade and Port Alice only uses sulphite processing. With no data on extent of effects and current patterns, only a basic assignment of moderate risk at sites directly adjacent to mills is possible (Table 2). The scope of industrial pollution is likely restricted and possibly affecting only Olympia Oyster sites directly adjacent to mills.

Marine shellfish aquaculture

Couch and Hassler (1989) found that the use of major growing areas previously used by Olympia Oysters for growing Pacific Oysters contributed to the decline of Olympia Oyster production in the U.S.; it is also possible that disturbance of former Olympia Oyster growing areas by intertidal clam harvests may be sufficient to prevent recolonization by oysters. However, Japanese Littleneck clams (*Ruditapes philippinarum*) are harvested primarily on the upper third of the intertidal zone, which minimizes impacts on Olympia Oysters in the lower third of the zone. Similarly, Pacific Oyster culture is primarily carried out in the upper and mid-intertidal zones. Olympia Oysters in Oregon have not been affected by Pacific Oyster culture (Johnson pers. comm. *in* Gillespie 1999). Large numbers exist in the shallow subtidal zone of oyster culture areas, and Olympia Oysters regularly settle on oyster shells left on the beach as cultch.

The presence of large numbers of Pacific Oysters can result in decreased survival of Olympia Oysters (Trimble *et al.* 2009). The combination of removal of dense beds of Olympia Oyster shell in the lower intertidal and subtidal zones, combined with the appearance of novel settlement substrate (Pacific Oyster beds) at higher levels of the intertidal zone acts as a settlement sink for Olympia Oyster larvae. Larvae that settle higher in the intertidal zone experience longer and more frequent exposure at low tide and even short increases in exposure (8% greater) resulted in 80% higher mortality relative to subtidal treatments. Surviving Olympia Oysters would also be lost to the system when cultured Pacific Oysters are harvested. Re-establishment of appropriate settlement substrate (oyster shell) at low intertidal and subtidal elevations has been recommended as habitat restoration in support of re-establishment of Olympia Oysters in Puget Sound (White *et al.* 2009a).

In areas on the B.C. coast having higher concentrations of shellfish aquaculture (e.g. Malaspina Inlet, Desolation Sound, Baynes Sound and Barkley Sound) reduction of adult numbers and the larval sink effect may be greater from this threat than in other areas (Table 2).

PROTECTION, STATUS, AND RANKS

Legal protection and status

Commercial oyster fisheries in British Columbia are currently regulated by the provincial Ministry of Fisheries and are for Pacific Oysters (*Crassostrea gigas*) only (Gillespie 1999, 2009). Commercial fishing for Olympia Oysters ceased in the 1930s, and none is currently contemplated. The daily bag limit for recreational fisheries under the *Federal Fisheries Act* and the *British Columbia Sport Fishing Regulations* was reduced by variation order to zero in May 2007 (DFO 2009).

Olympia Oysters are not listed by the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) (UNEP-WCMC 2009).

Following listing under *Species at Risk Act* (*SARA*) in 2003, Olympia Oysters were listed as a Special Concern species and a management plan was developed and posted to the SARA Registry (DFO 2009). Recommended management actions over the six-year term of the plan (2008–2013) were to maintain current restrictions on commercial and recreational harvest; address concerns for habitat alteration and transfer of non-indigenous predators and parasites; clarify threats to support protection measures; monitor abundance, including by establishment of index sites through collaborative effort; and communicate the detrimental effects of predator and parasite transfers.

The International Maritime Organization’s (IMO) *International Convention on the Control of Harmful Anti-fouling Systems on Ships* came into force in September 2008. The Convention stipulates that effective January 1, 2008, ships shall either not bear organotin compounds that act as biocides on their hulls or external parts or surfaces, or shall bear a coating that forms a barrier to such compounds leaching from underlying non-compliant antifouling systems (IMO 2001). Canada is a party to this convention. The Government of Canada prohibited the use of TBT in antifouling paint in January 2003, and proposed to add TBT to the Virtual Elimination List under the *Canadian Environmental Protection Act* (Environment Canada 2009).

Non-legal status and ranks

Olympia Oysters are currently included on the provincial Blue List of indigenous species of special concern (BCCDC 2009). Olympia Oysters were not on the *International Union for Conservation of Nature and Natural Resources* (IUCN) Red List in 1996 (Baillie and Groombridge 1996), and to date are not included in the on-line listing (IUCN 2009).

Habitat protection/ownership

The *Fisheries Act* contains provisions that can be applied to regulate the pollution of fish-bearing waters, and harmful alteration, disruption and destruction of fish habitat, which extends to the habitat of Olympia Oysters.

A number of protected areas, including Pacific Rim National Park Reserve and B.C. Provincial Parks and Ecological Reserves afford basic levels of protection for Olympia Oysters. The presence of Olympia Oysters in Klaskish Inlet on the west coast of Vancouver Island was a factor in establishing a provincial marine protected area in this area (Ellis and Emerson 1979; Biffard pers. comm. 2009).

Because Olympia Oysters live below the high tide line, most sites are Crown-owned. Some of these lands are tenured to aquaculture ventures through a provincial leasing policy.

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Authorities consulted

Doug Biffard and Susan Pollard, B.C. Ministry of Environment.

Alain Filion and Sonia Schnobb, Environment Canada.

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Gloria Goulet, Science Project Officer, ATK Coordinator, COSEWIC Secretariat.

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Simon Nadeau and Christie Whelan, Fisheries and Oceans Canada.

Meherzad Romer, B.C. Conservation Data Centre.

INFORMATION SOURCES

AMR (Archipelago Marine Research Ltd.). 2000. Subtidal survey of physical and biological features of Portage Inlet and the Gorge Waterway. Report for Victoria and Esquimalt Harbours Environmental Action Program, Capital Regional District, Victoria, B.C. 22 pp. + map folio.

Baillie, J., and B. Groombridge [eds.]. 1996. 1996 red list of threatened animals. International Union for the Conservation of Natural and Natural Resources, Species Survival Commission. Gland, Switzerland and Cambridge, U.K. 448 pp.

Baker, P. 1995. Review of ecology and fishery of the Olympia oyster, *Ostrea lurida* with annotated bibliography. The Journal of Shellfish Research 14(2):501–518.

Baker, P., N. Richmond, and N. Terwilliger. 2000. Re-establishment of a native oyster, *Ostrea conchaphila*, following a natural local extinction. Pp. 221–231. *In*: J. Pederson [ed.]. Marine bioinvasions. Proceedings of the First International Conference, January 24–27, 1999. MIT Sea Grant College Program, Cambridge, Massachusetts.

Barrett, E.M. 1963. The California oyster industry. California Department of Fish and Game Bulletin 123:103 pp.

BCCDC (British Columbia Conservation Data Centre). 2009. Species Summary: *Ostrea conchaphila*. B.C. Ministry of Environment. Web site: http://a100.gov.bc.ca/pub/eswp/ [accessed November 2009].

Behrens Yamada, S., and G.E. Gillespie. 2008. Will the European green crab (*Carcinus maenas*) persist in the Pacific Northwest? ICES Journal of Marine Science 65:725-729.

Benoit, Dan. 2011. *Email correspondence with Gerry Mackie*, 10 February 2010.

Bernard, F.R. 1968. Incidence and effect of the copepod *Mytilicola orientalis* Mori in the Pacific oyster of British Columbia. Fisheries Research Board of Canada Manuscript Report 993:14 pp.

Bernard, F.R. 1969. The parasitic copepod *Mytilicola orientalis* in British Columbia bivalves. Journal of the Fisheries Research Board of Canada 26:190–191.

Bernard, F.R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Canadian Special Publication of Fisheries and Aquatic Sciences 61:102 pp.

Bieler, R., J.G. Carter , and E.V. Coan. 2010. Classification of bivalve families. Pp. 113-133. In: Bouchet, P. and J.-P. Rocroi. 2010. Nomenclator of bivalve families. Malacologia 52(2):1–184.

Biffard, D. *Email correspondence to G. Gillespie.* 16 June 2009. B.C. Ministry of Environment, Victoria.

Blyth, C.A., J.W. McDonald, C.A. Horne, R.R. Canessa, and R. Kashino. 1997. Shellfish culture capability appraisal for Jervis Inlet. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 715 pp. + appendix.

Blyth, C.A., A.M. Peacock, C.A. Horne, and B.C. Kingzett. 1998. Shellfish aquaculture capability appraisal for the Queen Charlotte Islands region. Report submitted to B.C. Ministry of Fisheries, Victoria, B.C. 1123 pp. + appendix.

Bourne, N. 1978. Pacific oyster breeding in British Columbia, 1971, 1972, and 1973. Fisheries and Marine Service Technical Report 781:151 pp.

Bourne, N. 1997. Molluscan fisheries of British Columbia. NOAA Technical Report NMFS 128:115–130.

Bourne, N., and G. Cawdell. 1992. Intertidal clam survey of the North Coast area of British Columbia — 1990. Canadian Technical Report of Fisheries and Aquatic Sciences 1864:151 pp.

Bourne, N., and G.D. Heritage. 1979. Pacific oyster breeding in Pendrell Sound, 1974. Fisheries and Marine Service Technical Report 858:97 pp. + appendix.

Bourne, N.F., and G.D. Heritage. 1997. Intertidal clam surveys in British Columbia — 1992 and 1993. Canadian Technical Report of Fisheries and Aquatic Sciences 2168:95 pp.

Bourne, N., G.D. Heritage, and G. Cawdell. 1994. Intertidal clam surveys of British Columbia — 1991. Canadian Technical Report of Fisheries and Aquatic Sciences 1972:155 pp.

Bower, S.M., D. Hervio, and G.R. Meyer. 1997. Infectivity of *Mikrocytos mackini*, the causative agent of Denman Island disease in Pacific oysters, *Crassostrea gigas*, to various species of oysters. Diseases of Aquatic Organisms 29:111–116.

Bower, S.M, S.E. McGaldderry, and I.M. Price. 1994. Synopsis of infectious diseases and parasites of commercially exploited shellfish. Annual Review of Fish Disease 4:1–199.

Bower, S.M. and G.R. Meyer. 1994. Causes of mortalities among cultured Japanese scallops, *Patenopecten yessoensis*, in British Columbia. Pp. 85–91. *In:* N.F. Bourne, B.L. Bunting, and L.D. Townsend (eds .). Proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22–27, 1993. Volume 1. Canadian Technical Report of Fisheries and Aquatic Sciences 1994.

Bradley, W., and A.E. Seibert, Jr. 1978. Infection of *Ostrea lurida* and *Mytilus edulis* by the parasitic copepod *Mytlilicola orientalis* in San Francisco Bay, California. The Veliger 21(1):131–134.

Bright, D.A., and D.V. Ellis. 1990. A comparative survey of imposex in northeast Pacific neogastropods (Prosobranchia) related to tributyltin contamination, and choice of a suitable bioindicator. Canadian Journal of Zoology 68(9):1915–1924.

Brumbaugh, R.D., and L.D. Coen. 2009. Contemporary approaches for small-scale oyster reef restoration to address substrate versus recruitment limitation: a review and comments relevant for the Olympia oyster, *Ostrea lurida* Carpenter 1864. The Journal of Shellfish Research 28(1):147–161.

Buhle, E.R., and J.L. Ruesink. 2009. Impacts of invasive oyster drills on Olympia oyster (*Ostrea lurida* Carpenter 1864) recovery in Willapa Bay, Washington. The Journal of Shellfish Research 28(1):87–96.

Carl, G.C., and C.J Guiguet. 1957. Alien animals in British Columbia. British Columbia Provincial Museum Handbook 24:103 pp.

Carlton, J.T. and R. Mann. 1996. Transfers and world-wide introductions. Pp. 691–706. *In:* V.S. Kennedy, R.I.E. Newell and A.F. Eble (eds.). The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant College Publication UM-SG-TS-96-01.

Carnegie, R.B., G.R. Meyer, J. Blackbourn, N. Cochennec-Laureau, F.C.J. Berthe, and S.M. Bower. 2003. Molecular detection of the oyster parasite *Mikrocytos mackini*, and a preliminary phylogenetic analysis. Diseases of Aquatic Organisms 54:219-227.

Carpenter, J. *Email correspondence to G. Gillespie. 23 September 2009.* Heiltsuk Fisheries Program, Waglisla.

Carpenter, P.P. 1864. Diagnosis of new forms of Mollusca from the Vancouver district. Annals and Magazine of Natural History (series 3) 14(84):423–429; 15(85):28–32.

Chapman, W.M., and A.H. Banner. 1949. Contributions to the life history of the Japanese oyster drill, *Tritonalia japonica*, with notes on other enemies of the Olympia oyster, *Ostrea lurida*. Washington Department of Fisheries, Biology Report 49A: 168–200.

Coan, E.V., P. Valentich Scott ,and F.R. Bernard. 2000. Bivalve seashells of western North America. Marine bivalve mollusks from Arctic Alaska to Baja California. Santa Barbara Museum of Natural History Monographs No. 2. Studies in Biodiversity 2: 764 pp.

Coe, W.R. 1931. Spermatogenesis in the California oyster (*Ostrea lurida*). Biological Bulletin 61(3):309–315.

Coe, W.R. 1932a. Season of attachment and rate of growth of sedentary marine organisms at the pier of the Scripps Institute of Oceanography, La Jolla, California. Bulletin of the Scripps Institute of Oceanography, University of California Technical Series 3(3):37–86.

Coe, W.R. 1932b. Development of the gonads and the sequence of sexual stages in the California oyster (*Ostrea lurida*). Bulletin of the Scripps Institute of Oceanography, University of California Technical Series 3(6):119–144.

Cohen, A.N., J.T. Carlton, and M. Fountain. 1995. Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. Marine Biology 122:225–237.

COSEWIC. 2000. COSEWIC assessment and status report on the Olympia oyster *Ostrea conchaphila* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 30 pp.

Couch, D., and T.J. Hassler. 1989. Species Profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) — Olympia oyster. U.S. Fish and Wildlife Service Biological Report 82(11.124). U.S. Army Corps of Engineers, TR EL-82-4. 8 pp.

Cross, S.F., S.J. Gormican, and B.C. Kingzett. 1995. Shellfish culture capability appraisal for Quatsino Sound, Vancouver Island. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 413 pp. + appendix.

Cross, S.F., and B.C. Kingzett. 1993. Shellfish culture capability appraisal for Clayoquot Sound, Vancouver Island. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 373 pp. + appendix.

Dall, W.H. 1914. Notes on west American oysters. The Nautilus 28(1):1–3.

Dall, W.H. 1916. Checklist of the Recent bivalve mollusks (Pelecypoda) of the northwest coast of America from the Polar Sea to San Diego, California. Southwest Museum, Los Angeles, California. 44 pp.

DFO (Department of Fisheries and Oceans). 2009. Management plan for the Olympia oyster (*Ostrea conchaphila*) in Canada. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, Ottawa. vi + 31 pp.

Dimick, R.E., G. England, and J.B. Long. 1941. Native oyster investigations of Yaquina Bay, Oregon. Progress Report 2. Oregon Agricultural Experimentation Station. 153 pp.

Dinnel, P.A., B. Peabody, and T. Peter-Contesse. 2009. Rebuilding Olympia oysters, *Ostrea lurida* Carpenter 1864, in Fidalgo Bay, Washington. The Journal of Shellfish Research 28(1):79–85.

Edmondson, C.H. 1923. Shellfish resources of the northwest coast of the United States. Report to the U.S. Commissioner Fisheries (1922), Appendix 3. Bureau of Fisheries Document 920:21 pp.

Ellis, D.V., and B. Emerson. 1979. Native oysters, *Ostrea lurida*, in Checleset Bay. Report submitted to Ecological Reserves Unit, B.C. Department of Lands, Forests and Water Resources, Victoria. 11 pp.

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

Elsey, C.R. 1933. Oysters in British Columbia. Bulletin of the Biological Board of Canada 34: 34 pp.

Elsey, C.R. 1934. The Japanese oyster in Canadian Pacific waters. Fifth Pacific Science Congress:4121–4127.

Elsey, C.R. 1935. On the structure and function of the mantle and gill of *Ostrea lurida* and *Ostrea gigas*. Transactions of the Royal Society of Canada 48(5):131–160.

Environment Canada. 2009. Proposed risk management approach for non-pesticidal organotin compounds (organotins) (non-pesticidal organotins). Environment Canada, Health Canada, Ottawa. 15 pp.

Foster, N.R. 1991. Intertidal bivalves. A guide to the common marine bivalves of Alaska. University of Alaska Press, Fairbanks. 152 pp.

Friedman, C.S., H.M. Brown, T.W. Ewing, F.J. Griffin, and G.N. Cherr. 2005. Pilot study of the Olympia oyster *Ostrea conchaphila* in the San Francisco Bay estuary: description and distribution of diseases. Diseases of Aquatic Organisms 65:1–8.

Galtsoff, P.S. 1929. Oyster industry of the Pacific coast of the United States. Report to the U.S. Commissioner Fisheries (1929), App. VIII. Bureau of Fisheries Document 1066:367–400.

Gillespie, G.E. 1999. Status of the Olympia oyster, *Ostrea conchaphila*, in Canada. Canadian Stock Assessment Secretariat Research Document 99/150. 36 pp.

Gillespie, G.E. 2000. COSEWIC status report on the Olympia oyster *Ostrea conchaphila* in Canada. *In*: COSEWIC assessment and update status report on the Olympia oyster *Ostrea conchaphila* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 30 pp.

Gillespie, G.E. 2007. Distribution of non-indigenous intertidal species on the Pacific coast of Canada. Nippon Suisan Gakkaishi 73(6):1133–1137.

Gillespie, G.E. 2009. Status of the Olympia oyster, *Ostrea lurida* Carpenter 1864, in British Columbia, Canada. The Journal of Shellfish Research 28(1):59–68.

Gillespie, G.E., and N.F. Bourne. 1998. Exploratory intertidal clam surveys in British Columbia — 1997. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2465:43 pp.

Gillespie, G.E., and N.F. Bourne. 2000. Exploratory intertidal clam surveys in British Columbia — 1998. Canadian Manuscript Report for Fisheries and Aquatic Science 2508:98 pp.

Gillespie, G.E., and N.F. Bourne. 2005a. Exploratory intertidal bivalve surveys in British Columbia — 2002. Canadian Technical Report of Fisheries and Aquatic Sciences 2733:199 pp.

Gillespie, G.E., and N.F. Bourne. 2005b. Exploratory intertidal bivalve surveys in British Columbia — 2004. Canadian Technical Report of Fisheries and Aquatic Science 2734:144 pp.

Gillespie, G.E., N.F. Bourne, and B. Rusch. 2004. Exploratory intertidal bivalve surveys in British Columbia — 2000 and 2001. Canadian Technical Report for Fisheries and Aquatic Sciences 2681:120 pp.

Gillespie, G.E., A.C. Phillips, D.L. Paltzat, and T.W. Therriault. 2007. Status of the European green crab, *Carcinus maenas*, in British Columbia — 2006. Canadian Technical Report for Fisheries and Aquatic Sciences 2700:39 pp.

Grosholz, E.D., and G.M. Ruiz. 1995. Spread and potential impact of the recently introduced European green crab, *Carcinus maenas*, in central California. Marine Biology 122:239–247.

Grosholz, E.D., G.M. Ruiz, C.A. Dean, K.A. Shirley, J.L. Maron, and P.G. Connors. 2000. The impacts of a non-indigenous marine predator in a California bay. Ecology 81(5):1206–1224.

Groth, S., and S. Rumrill. 2009. History of Olympia oysters (*Ostrea lurida* Carpenter 1864) in Oregon estuaries and a description of recovering populations in Coos Bay. The Journal of Shellfish Research 28(1):51–58.

Haderlie, E.C., and D.P. Abbott. 1980. Bivalvia: the clams and allies. Pp. 355–411. *In:* R.H. Morris, D.P. Abbott and E.C. Haderlie (eds.). Intertidal Invertebrates of California. Stanford University Press, Stanford, California.

Hanski, I,. and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnaean Society 42:3–16.

Harbo, R.M. 1997. Shells and Shellfish of the Pacific Northwest. Harbour Publishing, Madiera Park, B.C. 270 pp.

Harry, H.W. 1985. Synopsis of the supraspecific classification of living oysters (Bivalvia: Gryphaeidae and Ostreidae). The Veliger 28(2):121–158.

Herborg, L.-M., and T.W. Therriault. 2007. Risk assessment for two solitary and three colonial tunicates in both Atlantic and Pacific Canadian waters. Canadian Science Advisory Secretariat Research Document 2007/063:64 pp.

Heritage, G.D., and N. Bourne. 1979. Pacific oyster breeding in British Columbia 1977. Fisheries and Marine Service Technical Report 882:139 pp. + appendix.

Heritage, G.D., N. Bourne, and D.W. Smith. 1977. Pacific oyster breeding in British Columbia, 1976. Fisheries Research Board of Canada Manuscript Report 1419:49 pp.

Heritage, G.D., P.A. Breen, and N.F. Bourne. 1976. Pacific oyster breeding in Pendrell Sound, 1975. Fisheries Research Board of Canada Manuscript Report 1406:91 pp.

Heritage, G.D., G.E. Gillespie, and N.F. Bourne. 1998. Exploratory intertidal clam surveys in British Columbia — 1994 and 1996. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2464:114 pp.

Hopkins, A.E. 1935. Attachment of larvae of the Olympia oyster, *Ostrea lurida*, to plane surfaces. Ecology 16(1):82–87.

Hopkins, A.E. 1936. Ecological observations on spawning and early larval development in the Olympia oyster (*Ostrea lurida*). Ecology 17(4):551–566.

Hopkins, A.E. 1937. Experimental observations on spawning, larval development and setting in the Olympia oyster *Ostrea lurida*. Bulletin of the U.S. Bureau of Fisheries 48:438–503.

Hopkins, A.E., P.S. Galtsoff, and H.C. McMillin. 1935. Effects of pulp mill pollution on oysters. Bulletin of the U.S. Bureau of Fisheries 47:125–162.

IMO (International Marine Organization). 2001. International Convention on the Control of Harmful Anti-Fouling Systems on Ships. International Maritime Organization, London. http://www.imo.org/conventions/mainframe.asp?topic_id=529

IUCN (International Union for Conservation of Nature). 2009. IUCN Red List of Threatened Species. Version 2009.2. http://www.iucnredlist.org [accessed November 2009].

Jamieson, G.S., E.D. Grosholz, D.A. Armstrong, and R.W. Elner. 1998. Potential ecological implications from the introduction of the European green crab, *Carcinus maenas* (Linnaeus), to British Columbia, Canada and Washington, USA. Journal of Natural History 32:1587–1598.

Jones, R. *Personal communication to G. Gillespie 2009*. Haida Fisheries Program, Masset.

Kingzett, B.C., S.J. Gormican, and S.F. Cross. 1995a. Shellfish culture capability appraisal for Nootka Sound, Vancouver Island. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 603 pp. + appendix.

Kingzett, B.C., S.J. Gormican, and S.F. Cross. 1995b. Shellfish culture capability appraisal for Kyuquot Sound, Vancouver Island. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 252 pp. + appendix.

Kingzett, B.C., S.J. Gormican, and S.F. Cross. 1995c. Shellfish culture capability appraisal for Okeover Inlet region. Report submitted to B.C. Ministry of Agriculture, Fisheries and Food, Victoria, B.C. 223 pp. + appendix.

Kirkendale, L., T. Lee, P. Baker, and D.Ó Foighil. 2004. Oysters of the Conch Republic (Florida Keys): a molecular phylogenetic study of *Parahyotissa mcgintyi*, *Teskeyostrea weberi* and *Ostreola equestris*. Malacologia 46:309–326.

Kozloff, E.N. 1974. Keys to the Marine Invertebrates of Puget Sound, the San Juan Archipelago and Adjacent Regions. University of Washington Press, Seattle, Washington. 226pp.

Lamb, A., and B.P. Hanby. 2005. Marine life of the Pacific Northwest. A photographic encyclopedia of invertebrates, seaweeds and selected fishes. Harbour Publishing, Madeira Park, B.C. 398 pp.

Lapègue, S., I.B. Salah, F.M. Batista, S. Heurtebise, L. Neifar, and P. Boudry. 2006. Phylogeographic study of the dwarf oyster, *Ostreola stentina*, from Morocco, Portugal and Tunisia: evidence of a geographic disjunction with the closely related taxa, *Ostrea aupouria* and *Ostreola equestris*. Marine Biology 150:103–110.

Lee, J.C., and N. Bourne. 1977. Marine resource inventory of Pacific Rim National Park — 1976. Fisheries and Marine Service Manuscript Report 1436:375 pp.

Lindsay, C.E., and D. Simons. 1997. The fisheries for Olympia oysters, *Ostreola conchaphila*; Pacific oysters, *Crassostrea gigas*; and Pacific razor clams, *Siliqua patula*, in the state of Washington. NOAA Technical Report NMFS 128:89–113.

Loosanoff, V.L., and H.C. Davis. 1963. Rearing of bivalve mollusks. Advances in Marine Biology 1:1–136.

Marriage, L.D. 1958. The bay clams of Oregon. Fisheries Commission of Oregon Educational Leaflet 2 :29 pp.

McDonald, P.S., G.C. Jensen, and D.A. Armstrong. 2001. The competitive and predatory impacts of the non-indigenous crab *Carcinus maenas* (L.) on early benthic Dungeness crab *Cancer magister* Dana. Journal of Experimental Marine Biology and Ecology 258:39–54.

McKernan, D.L., V. Tartar, and R. Tollefson. 1949. An investigation of the native oyster industry in Washington, with special reference to the effects of sulfite pulp mill waste on the Olympia oyster (*Ostrea lurida*). Washington Department of Fisheries, Biology Report 49A:115–165.

Meyer, G. *Email correspondence to G. Gillespie.* 30 August 2010. Fisheries and Oceans Canada, Nanaimo, B.C.

Meyer, G.R., G.J. Lowe, E. Kim, C.L. Abbott, S.C. Johnson, and S.R. Gilmore. 2010. Health status of Olympia Oysters (*Ostrea lurida*) in British Columbia. Canadian Journal of Shellfish Research 29(1):181–185.

Mix, M.C. 1975. Proliferative characteristics of atypical cells in native oysters (*Ostrea lurida*) from Yaquina Bay, Oregon. Journal of Invertebrate Pathology 26:289–298.

Mix, M.C. ,and V. Sprague. 1974. Occurrence of a haplosporidian in native oysters (*Ostrea lurida*) from Yaquina Bay, Oregon. Journal of Invertebrate Pathology 23:252–254.

Nelson, A.R., A.E. Jennings, and K. Kasima. 1996. An earthquake history derived from stratigraphic and microfossil evidence of relative sea level change at Coos Bay, southern coastal Oregon. Bulletin of the Geological Society of America 108:141-154.

Newcombe, C.F. 1891. Report on the marine shells of British Columbia. Bulletin of the Natural History Society of British Columbia 1:31–72.

Norgard, T.C., S. Davies, L.M. Stanton, and G.E. Gillespie. 2010. Evaluation of survey methodologies for monitoring Olympia oyster (*Ostrea lurida* Carpenter, 1864) populations in British Columbia. Canadian Science Advisory Secretariat Research Document 2010/006:iv + 56 pp.

Odlaug, T.O. 1949. Effects of stabilized and unstablilized waste sulfite liquor on the Olympia oyster, *Ostrea lurida*. Transactions of the American Microscopical Society 68(2):163–182.

Palacios, K.C,. and S.P. Ferraro. 2003. Green crab (*Carcinus maenas* Linnaeus) consumption rates on and prey preferences among four bivalve prey species. The Journal of Shellfish Research 22(3):865–871.

Parks Canada. 2008. State of the park report — Pacific Rim National Park Reserve. Parks Canada, Ottawa. 62 pp.

Paul, A.J., and H.M. Feder. 1976. Clam, mussel and oyster resources of Alaska. University of Alaska Institute of Marine Science Report 76-4:41 pp.

Peacock, A.M., C.A. Blyth, C.A. Horne, F.A. Williams, S.F. Cross, and S.J. Gormican. 1998. Shellfish culture capability appraisal for the northern Central Coast region. Report submitted to B.C. Ministry of Fisheries, Victoria, B.C. 103 pp. + appendix.

Polson, M.P., W.E. Hewson, D.J. Eernisse, P.K. Baker,and D.C. Zacherl. 2009. You say *conchaphila*, I say *lurida*: molecular evidence for restricting the Olympia oyster (*Ostrea lurida* Carpenter 1864) to temperate western North America. The Journal of Shellfish Research 28(1):11–21.

Polson, M.P., and D.C. Zacherl. 2009. Geographical distribution and intertidal population status for the Olympia oyster, *Ostrea lurida* Carpenter 1864, from Alaska to Baja. The Journal of Shellfish Research 28(1):69–77.

Quayle, D.B. 1960. The intertidal bivalves of British Columbia. British Columbia Provincial Museum Handbook 17:104 pp.

Quayle, D.B. 1964. Distribution of introduced marine Mollusca in British Columbia waters. Journal of the Fisheries Research Board of Canada 21:1155–1181.

Quayle, D.B. 1969. Pacific oyster culture in British Columbia. Fisheries Research Board of Canada Bulletin 169:192 pp.

Quayle, D.B. 1974. Pendrell Sound oyster breeding 1950–1970. Fisheries Research Board of Canada Manuscript Report Data Series 1291:389 pp.

Quayle, D.B. 1988. Pacific oyster culture in British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 218:241 pp.

Robinson, A.M. 1997. Molluscan fisheries in Oregon: past, present, and future. NOAA Technical Report NMFS 128:75–87.

Seale, E.M. and D.C. Zacherl. 2009. Seasonal settlement of Olympia oyster larvae, *Ostre,a lurida* Carpenter 1864 and its relationship to seawater temperature in two southern California estuaries. Journal of Shellfish Research 28(1):113–120.

Shaw, W.N. 1997. The shellfish industry of California — past, present and future. NOAA Technical Report NMFS 128:57–74.

Sherwood, H.P. 1931. The oyster industry of North America: a record of a brief tour of some of the centres on the Atlantic and Pacific coasts, and of a summer in Canada. Journal of Conservation 6(3):361–386.

Shilts, H.M., M.S. Pascual, and D.Ó Foighil. 2007. Systematic, taxonomic and biogeographic relationship of Argentine flat oysters. Molecular Phylogenetics and Evolution 44:467–473.

Sloan, N.A., F.M. Bartier, and W.C. Austin. 2001. Living marine legacy of Gwaii Haanas II: marine invertebrate baseline to 2000 and invertebrate-related management issues. Parks Canada Technical Reports in Ecosystem Science 35:331 pp.

Stafford, J. 1913a. Conservation of the oyster. Province of British Columbia Report on Commercial Fisheries (1912):71–80.

Stafford, J. 1913b. The Canadian Oyster. Its Development, Environment and Culture. Commission of Conservation Canada, Ottawa. 159 pp.

Stafford, J. 1914. The native oyster of British Columbia (*Ostrea lurida*, Carpenter). Province of British Columbia Report on Commercial Fisheries (1913):79–102.

Stafford, J. 1915. The native oyster of British Columbia (*Ostrea lurida*, Carpenter). Province of British Columbia Report on Commercial Fisheries (1914):100–119.

Stafford, J. 1916. The native oyster of British Columbia (*Ostrea lurida*, Carpenter). Province of British Columbia Report on Commercial Fisheries (1915):141–160.

Stafford, J. 1917. The native oyster of British Columbia (*Ostrea lurida*, Carpenter). Province of British Columbia Report on Commercial Fisheries (1916):88–120.

Stanton, L.M., T.C. Norgard, S.E.M. MacConnachie, and G.E. Gillespie. In prep. Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia — 2009. Canadian Technical Report for Fisheries and Aquatic Science.

Stein, J.E., J.G. Denison, and J.G. Mackin. 1959. *Hexamita* sp. and an infectious disease in the commercial oyster, *Ostrea lurida*. Proceedings of the National Shellfisheries Association 50:67–81.

Steele, E.N. 1957. The Rise and Decline of the Olympia Oyster. Fulco Publishing, Elma, Washington. 126 pp.

Strathman, M.F. 1987. Reproduction and Development of Marine Invertebrates of the Northern Pacific Coast. University of Washington Press, Seattle, Washington. 670 pp.

Sutherland Brown, A. 1968. Geology of the Queen Charlotte Islands, British Columbia. British Columbia Department of Mines and Petroleum Resources Bulletin 54:226 pp.

Taylor, D.L. 2005. Predatory impact of the green crab (*Carcinus maenas* Linnaeus) on post-settlement winter flounder (*Pseudopleuronectes americanus* Walbaum) as revealed by immunological dietary analysis. Journal of Experimental Marine Biology and Ecology 324:112–126.

Taylor, G.W. 1895. Preliminary catalogue of the marine Mollusca of the Pacific coast of Canada, with notes upon their distribution. Transactions of the Royal Society of Canada, Second Series 1(Section 4):17–100.

Thain, J.E., and M.J. Waldock. 1986. The impact of tributyl tin (TBT) antifouling paints on molluscan fisheries. Water Science and Technology 18:193–202.

Therriault, T.W., L.-M. Herborg, A. Locke, and C.W. McKindsey. 2008. Risk assessment for European green crab (*Carcinus maenas*) in Canadian waters. Canadian Science Advisory Secretary Research Document 2008/042:40 pp.

Thompson, J. 1996. Snail's pace recovery from restricted toxic paint. Institute of Ocean Sciences Fact Sheet. Sidney, B.C. 2 pp.

Thompson, W.F. 1914. Report on the shellfish beds of British Columbia (clams, mussels and scallops). Province of British Columbia Report on Commercial Fisheries (1913):103–125.

Townsend, C.H. 1893. Report of observations respecting the oyster resources and oyster fishery of the Pacific coast of the United States. U.S. Commission of Fish and Fisheries, Report to the Commissioner (1889–1891):343–372.

Trimble, A.C., J.L. Ruesink, and B.R. Dumbauld. 2009. Factors preventing the recovery of a historically overexploited shellfish species, *Ostrea lurida* Carpenter 1964. Journal of Shellfish Research 28(1):97–106.

Turgeon, D.D., J.F. Quinn, Jr., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione ,and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Molluscs. 2nd Edition. American Fisheries Society Special Publication 26:ix + 526 pp.

UNEP-WCMC. 2009. UNEP-WCMC Species Database: CITES-Listed Species. http://www.cites.org/eng/resources/species.html [accessed November 2009].

White, J.M., E.R. Buhle, J.L. Ruesink, and A.C. Trimble. 2009a. Evaluation of Olympia oyster (*Ostrea lurida* Carpenter 1864) status and restoration techniques in Puget Sound, Washington, United States. The Journal of Shellfish Research 28(1):107-112.

White, J., J.L. Ruesink, and A.C. Trimble. 2009b. The nearly forgotten oyster: *Ostrea lurida* Carpenter 1864 (Olympia oyster) history and management in Washington State. The Journal of Shellfish Research 28(1):43–49.

Woelke, C.E. 1956. The flatworm *Pseudostylochus ostreophagus* Hyman. Proceedings of the National Shellfisheries Association 47:62–67.

World Conservation Monitoring Center. 1998. Checklist of CITES species. Gland, Switzerland. 312 pp.

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Graham Gillespie leads the Intertidal Clam Assessment, Aquatic Invasive Species and Crab Assessment Programs in the Marine Ecosystems and Aquaculture Division at the Pacific Biological Station, Nanaimo, B.C., for Fisheries and Oceans Canada. He prepared the initial status evaluation of Olympia Oysters for COSEWIC in 2000. His recent work has concentrated on survey methodology and population assessment techniques for commercially important and at-risk bivalve species and non-indigenous intertidal species. He has also conducted cephalopod assessments, focusing on Neon Flying Squid, Humboldt Squid and octopus, and developed assessments of the potential for commercial fisheries for Sea Mussels and Varnish Clams in British Columbia. Prior to joining the Shellfish Section in 1994, he worked on groundfish research, focusing on offshore rockfish stocks. He earned a B.Sc. in zoology from the University of Victoria in 1985. He is a member of the National Shellfisheries Association, and former executive member of their Pacific Coast Section.

COLLECTIONS EXAMINED

Royal British Columbia Museum, Victoria, British Columbia (see Table 1 for holdings).

Canadian Museum of Nature, Gatineau, Quebec (see Table 1 for holdings).