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Canadian Science Advisory Secretariat
Pacific Region — Science Response 2014/005

INTERIM ADVICE FOR THE DEVELOPMENT OF SEA CUCUMBER (*PARASTICHOPUS CALIFORNICUS*) AQUACULTURE IN BRITISH COLUMBIA

Context

There is increasing interest in culturing native California Sea Cucumber (*Parastichopus californicus*) in British Columbia (BC). Sea Cucumber aquaculture in BC is in the early stages of developing hatchery stock production and grow-out techniques. A range of potential aquaculture activities are being proposed by various proponents, including suspended and benthic containment, as well as uncontained Sea Cucumber ranching on the seafloor. Science advice was requested by the Aquaculture Management Division in November 2011, for the provision of advice by the fall of 2012, in the form of a review of current knowledge that would provide guidance and advice around the development of Sea Cucumber aquaculture activities in BC. Specifically, Fisheries and Oceans Canada (DFO) Science was asked:

1. how the various Sea Cucumber aquaculture activities would interact with different life stages of wild Sea Cucumber stocks;
2. what is the scale and direction of any interaction on the status and conservation objectives of wild Sea Cucumber stocks; and
3. what are the consequences of such culture activities on fish habitat and ecosystem function.

There is currently little to no science information available to address these questions. A review of the science request resulted in a response that fulsome advice could not be provided on these issues in the timeframe requested. A two-year research project, '*Ecological interactions between benthic-ranched and wild California Sea Cucumbers*,' was initiated in May 2012 with funding from the Aquaculture Collaborative Research and Development Program (ACRDP). Provision of advice, in the form of a comprehensive Canadian Science Advisory Secretariat (CSAS) Research Document, was deferred pending the completion of the research project expected in May 2014, with a CSAS regional peer review potentially achievable in the fall of 2014.

Considering the urgency of the request for advice, a *Science Special Response Process* (SSRP) was initiated based on the current existing knowledge of Sea Cucumber biology, ecology and behaviour to address the following points:

1. identify potential risks to wild Sea Cucumber stocks from various scenarios of Sea Cucumber aquaculture;
2. provide advice and recommendations, based on existing knowledge of Sea Cucumber biology and behaviour, for the development of Sea Cucumber aquaculture; and
3. Identify research priorities.

This Science Response Report results from the Science Response Process of October 2013 on the Interim Advice for the Development of Sea Cucumber (*P. californicus*) Aquaculture in British Columbia.

Background

California Sea Cucumber Biology and Ecology

Parastichopus californicus is an abundant species of Sea Cucumber in the northeastern Pacific Ocean with a range extending from Alaska to California (Lambert 1997). They are found from the intertidal to depths of over 250 meters (Lamb and Hanby 2005), preferring complex substrates such as bedrock, boulders, gravel or crushed shell (Campagna and Hand 2004). These animals are deposit feeders, adapted to consume particulate material, and feed randomly using adhesive mucus-coated oral tentacles which scoop food material into the mouth (Cameron and Fankboner 1984). Bacteria and fungi associated with detrital particles are the main food source (Yingst 1976). *P. californicus* are mobile, with observed displacement of up to 20.2 metres per day (Cieciel 2004), largely in search of food. Reproduction occurs through broadcast spawning and planktonic fertilization of gametes followed by a 7-17 week planktonic larval period. A genetic study in 2002 (C. Hand, DFO, unpublished data) showed generally high levels of gene flow, but potential for genetic differences between hydrographically-isolated populations. There are no known diseases in wild populations of *P. californicus*, but several parasites have been identified (Lambert 1997). Attempts at aging and tagging have not been successful and, as a result, there are gaps in knowledge on longevity, recruitment, growth, age at recruitment and migration patterns. Recent juvenile growth studies indicate that animals are slow growing and that over five years are needed for animals to reach market size (Hannah et al. 2012, Duprey et al. 2012).

Commercial Fishery of the California Sea Cucumber

Sea Cucumbers have been harvested in BC since 1971. In 1995, the Sea Cucumber commercial fishery in BC underwent evaluation as a data-limited fishery and began its development under the Phased Approach for new and developing invertebrate fisheries (Perry et al. 1999). The objective was to define an assessment framework to enable biologically-based stock assessment and risk-averse fishery management. A rigorous 10-year period of restricted harvest, surveys, experimental fisheries and information review began in 1997 in collaboration with commercial licence holders and First Nations. Subsequently, recommendations to allow the fishery to expand (Hand et al. 2009) were endorsed by the Invertebrate Subcommittee of the Pacific Scientific Advice Review Committee (DFO 2008) and areas have been re-opening throughout the coast since 2008. The coastwide commercial fishery quota was 616.7 t in the 2011/2012 fishery year, with a landed value of approximately $7M.

The Assessment Framework for *P. californicus* in BC is described in Duprey et al. (2011) and includes methods for estimating linear density (i.e., Sea Cucumbers per meter of shoreline) and mean animal weight, with recommendations for sustainable harvest rates. Sea Cucumber biomass estimates are calculated at the Pacific Fishery Management (PFM) Subarea level as the product of linear density, mean weight and shoreline length. A recommended annual harvest rate, in the range of 3.5 - 10.3%, is applied to estimates of biomass to calculate the Total Allowable Catch (Hand et al. 2009, Duprey et al. 2011).

California Sea Cucumber Aquaculture

Although wild Sea Cucumber harvest has occurred in BC since 1971, interest in Sea Cucumber aquaculture on the BC coast is more recent. There are currently three hatchery sites and nine grow-out sites which were licensed by the Province of BC prior to December 2010, when DFO assumed authority to regulate aquaculture in BC. Since that time, an additional four hatcheries and five grow-out sites have been licensed by DFO, and approximately 22 new applications or applications to have Sea Cucumber added to existing licences have been submitted for review.

Existing or proposed aquaculture grow-out methodology includes growing juveniles in suspended or benthic containment systems, either alone or in combination with other species at different trophic levels [termed Integrated Multi-Trophic Aquaculture (IMTA)], or on the sea floor without containment. Animals in on-bottom grow-out may be contained by netting off the entrance to natural bays, fencing below finfish/shellfish farms or benthic cages, or they may be uncontained with the assumption that the animals will remain in the area due to increased availability of organic detritus (especially around finfish/shellfish farms). There are potential benefits of using Sea Cucumbers at shellfish/finfish farms in IMTA; this includes consumption of cultured animal wastes and uneaten feeds and re-working of the sediment through feeding and movement, both processes potentially leading to a decrease in organic levels and anoxic conditions (Slater and Carton 2009, Nelson et al. 2012, Hannah et al. 2013).

Stocking methodologies at grow-out sites have, to date, been through the collection of wild juveniles that settle on floating aquaculture gear, such as oyster strings, clam/oyster trays and pearl nets and from the benthos of the licensed area. These animals are moved into protected areas where they are held until they have grown to market size (on-growing). Conditions of all shellfish aquaculture licences provide the authority for the licence holder to retain wild-set individuals of a licenced species and to harvest those as by-catch to their aquaculture crop. Hatchery technology is in the early stages of development and, although successful hatchery spawnings have occurred in BC, there have been no known instances of successful rearing of juveniles to the sizes needed for outplanting. Most applications for Sea Cucumber aquaculture licences are non-specific about stocking conditions or specify collection of wild-set juveniles for on-growing.

Analysis and Response

The various Sea Cucumber aquaculture practices being proposed are associated with potential risks to wild *P. californicus* populations. These activities are addressed in two broad categories which are considered in detail in the following sections:

1. Collection of wild-settled juveniles from licensed area; and
2. Effects of culture activities on wild stocks

Collection of wild-settled juveniles from the licensed area

The DFO Policy on Access to Wild Aquatic Resources, as it applies to Aquaculture (DFO 2004), allows access to wild stocks in situations where hatchery technology for the species being cultured does not exist, in order to foster development and expansion of the Canadian aquaculture industry. Since hatchery production of California Sea Cucumbers has not yet become reliable, the existing license holders who are licensed for Sea Cucumber are permitted to collect animals that have naturally settled on hanging gear within the licensed area for grow-out to market size.

There are many unknowns regarding settlement and early survival of juvenile Sea Cucumbers in the wild or on aquaculture structures. Culture gear hanging in the water column may collect planktonic Sea Cucumber larvae passively (i.e., increased area for the larvae to settle on, combined with decreased tidal current velocity around the gear) or through physical or biochemical settlement cues associated with the gear itself or the biofouling community that develops on these structures. It is therefore possible that aquaculture farms in general could act as a larval settlement sink, reducing the amount of Sea Cucumber larvae that settle in surrounding wild habitats.

Alternatively, these aquaculture structures may provide good settlement surfaces and recruitment environments in areas where the benthic habitat is not appropriate for settling Sea Cucumber larvae. These naturally-set juvenile Sea Cucumbers may experience lower predation rates by settling in cryptic habitat and physical separation from large benthic predators. The juveniles on the farm may grow and survive better than counterparts in the wild, due to increased organic loading around finfish/shellfish facilities, reaching sexual maturity faster. Adults may also produce more eggs/sperm due to this increased organic loading and/or have higher rates of fertilization due to increased proximity to one another or reduced currents around the farm gear. Thus, if wild-set individuals on the farm grow to reproductive size, they may have a higher fecundity than their wild counterparts. The resultant farm-derived larvae can then potentially recruit back into the wild population. In addition, the naturally-set juveniles on the farm (either on the gear or on the sea floor) may emigrate from the site and recruit back into surrounding wild habitats. However, since it is anticipated that Sea Cucumber culture will co-occur with other cultured organisms, it should be noted that these animals will be entering into a benthic ecosystem that has increased organic loading, which both attracts an increased number of predators (D’Amours et al. 2008) and may keep surviving individuals from migrating away. Indeed, adult Sea Cucumber densities are often reported to be higher under active shellfish facilities (Ken Ridgway, Pacific Sea Cucumber Harvesters Association, pers. comm.). If predation rates of Sea Cucumbers that fall off the gear are high, the benefits from the protection and increased growth rates that the animals experienced in earlier life cycle stages may be reduced or negated.

Present Sea Cucumber aquaculture activities are reliant on the wild population successfully producing viable larvae which settle and recruit on the aquaculture equipment, other cultured species or seabed beneath the aquaculture facility. The impact of this activity on natural recruitment levels into the wild Sea Cucumber population has not been assessed, but it could possibly lead to reduced wild stock productivity since these animals will not be able to recruit back into the wild population.

Effects of Culture Activities on Wild Stocks

Wild population sink

In a scenario where aquaculture licenses include Sea Cucumbers with other cultured species and where there are no exclusion structures or barrier separating wild and cultured populations, the high levels of organic detritus under aquaculture sites may serve to actively attract the mobile adult wild Sea Cucumbers. Many of the current Sea Cucumber aquaculture licence holders are permitted to collect any Sea Cucumber regardless of whether they are on aquaculture gear or on the benthos within the licensed area. Since it is currently not possible to differentiate animals that have migrated into the licensed site from animals falling off the hanging lines/nets above the benthic habitat or from seeded stock, there is a concern that wild animals will continuously migrate into the licensed area to access nutrient-rich food sources and will be harvested along with cultured product. Therefore, harvesting by aquaculturists at grow-out sites may have a greater impact on wild populations than would be expected based on tenure size alone.

A scenario where hatchery-reared juveniles are released to free-range on licensed area also poses a potential a conservation concern because of the unproven survivability of these juveniles. Should these animals not survive, the result may be the harvest of wild Sea Cucumbers under the mistaken belief that they are cultured animals. Even if a threshold of removal was imposed, the in- and out-migration would be hard to quantify, resulting in an unknown origin of stock harvested. This, combined with unknowns of survivability of hatchery raised stock, could potentially lead to mostly wild individuals being harvested.

If hatchery-reared animals are fully contained, and adult wild stock is not able to enter the enclosures, there should be little interaction between wild stocks and aquaculture activities. In this scenario, it is likely that the hatchery-reared animals would positively affect the wild population through their reproductive output as they matured (assuming cultured cucumbers are harvested sometime after they reach maturity). Since Sea Cucumbers are capable of climbing submerged vertical surfaces, the containment structures would need to be closed on all sides with a mesh size that precludes escape. Methods to ensure that an effective barrier is created are being explored through ongoing research projects.

Disease issues with hatchery-reared animals

There are no published records of diseases in *P. californicus* in BC and there has been little concern for the wild stocks to date. However, hatcheries and grow-out sites maintaining artificially high stocking densities may increase the risk of introduction of new diseases and the risk of transmission to wild populations. In China, where Sea Cucumber aquaculture has grown to be a huge industry, studies have found a number of diseases resulting from stress due to high temperature and density that can rapidly transfer to healthy individuals and lead to high mortality, up to 80% in certain cases (e.g., Yin-Geng et al. 2004). Severe parasite infection has also been found in cultured Sea Cucumber stock, causing increased mortality (Lambert 1997).

Movement of broodstock and progeny should not occur between established Shellfish Transfer Zones, as defined by the Introductions and Transfers Committee (Appendix 1), to reduce the potential risk of disease or parasite transfer to other populations.

Genetic concerns with hatchery-reared animals

It is expected that efforts to produce juvenile Sea Cucumbers will ultimately succeed and that outplanted animals will survive and spawn successfully before being harvested. The development of robust protocols directing the location of broodstock collection, the minimum number of broodstock to collect, the number of broodstock spawned, the number of spawning events and the refresh rate of broodstock are required in order to minimize the potential for genetic-drift and loss of genetic fitness in wild stocks from hatchery introductions. Guidelines to manage the lineage and outplanting of juveniles from hatchery production have been recommended for the Geoduck (*Panopea generosa*) clam aquaculture industry (DFO 2013). Given the similarity in early lifecycle characteristics between the two species, it is recommended that protocols for Sea Cucumber be modeled on those recommended for Geoduck aquaculture.

Movement of broodstock and progeny should not occur between established Shellfish Transfer Zones to retain the genetic characteristics of local populations. Since we know little about the genetic make-up of Sea Cucumber populations, a more conservative restriction of limiting the outplanting of juveniles to the same PFM Subarea from which broodstock were collected is recommended.

Impact on assessment of wild stocks

As noted, aquaculturists have legal access to wild animals found within the lease area for those species listed on their licence, and may harvest 100% of these animals as by-catch to the harvest of the aquaculture crop. Such removals of Sea Cucumbers should be incorporated into estimates of wild stocks during determination of sustainable quotas for different PFM Subareas. This conservation concern may be mitigated if the lease is seeded with hatchery-reared juveniles that survive to adult size.

De-fouling of aquaculture gear

It is common practice during shellfish aquaculture maintenance and harvest operations to clean the gear of fouling organisms, including juvenile Sea Cucumbers, with pressure washing, manual scraping or air drying. These practices may cause fatal injuries to juvenile Sea Cucumbers, and there have been anecdotal accounts of large numbers of dead juvenile Sea Cucumbers seen on decks and docks after these cleaning events. The potential impact to wild populations could be significant, considering that there are several hundred shellfish licences in BC, and a method to quantify these removals from the wild system is needed.

Conclusions and Recommendations

Increased knowledge on the growth and survival of hatchery-produced Sea Cucumbers, and their potential interactions with the wild population, is important to the development of policy and management that will foster economic prosperity, as well as management transparency, for the developing Sea Cucumber aquaculture sector. Currently, there is considerable scientific uncertainty on the viability and impacts of large-scale expansion of *P. californicus* aquaculture in BC. Further research is required to assess the potential for successful Sea Cucumber aquaculture that meets DFO objectives for conservation and environmental sustainability. It may well be found that risks to the wild population of increased incidental harvest by aquaculturists and loss of available biomass to the wild fishery, as a result of tenures/licensed areas occupying shoreline, are mitigated by the introduction of hatchery-raised stock and/or increased survival, growth and reproduction of natural stock through increased food availability on farm sites. Scientific research will be required to answer this question.

To lay the foundation for a risk-averse and sustainable aquaculture fishery, it is recommended that Sea Cucumber aquaculture proceed with a phased approach which allows industry development and access to wild Sea Cucumber stocks, while providing opportunities for scientific research and information gathering. A ‘learn-as-you-go’ approach was followed during the development of the wild Sea Cucumber commercial fishery in collaboration with the Pacific Sea Cucumber Harvesters Association. Similarly, Geoduck aquaculture is currently undergoing a phased development.

The following mitigation measures, taking into consideration existing information gaps, are recommended. Recommendations for the mitigation of potential risks to wild Sea Cucumber stocks from the developing Sea Cucumber aquaculture fishery in BC, presented here, are modeled on the approach recommended for Geoduck aquaculture in BC (DFO 2013). Specifically, the following is recommended:

1. New Sea Cucumber aquaculture operations occur in approved contained cultivation structures or using approved technologies (e.g., trays, cages or nets that keep cultured Sea Cucumbers in and wild Sea Cucumbers out), irrespective of whether cultured stock origin is from hatchery or wild set with transfer. Free range release of hatchery-reared juveniles would not allow any knowledge to be gained on the survival and growth of hatchery-reared juveniles, or on the potential for success of the Sea Cucumber aquaculture industry. Contained cultivation operations would allow health monitoring, detection of high mortality and would mitigate potential negative impacts to wild populations.
2. Collect a minimum of 100 Sea Cucumbers for brood stock for each hatchery. Not all collected brood stock are expected to survive to spawning, and not all surviving animals are expected to spawn; therefore, it is recommended that the number of individuals collected for brood stock be higher that the number required for spawning.
3. Use a minimum of 60 Sea Cucumbers when conducting hatchery spawnings (ideally 1:1 sex ratio) to mitigate risks of genetic diversity loss. Genetic analysis of brood stock and associated seed is recommended to estimate effective spawning population size in order to determine if this number is adequate.

4. Collect all brood stock, for each hatchery, from wild Sea Cucumber populations and replace brood stock annually with fresh brood stock, in order to maximize genetic diversity of hatchery produced seed and reduce possible genetic impacts of out-planted Sea Cucumber on wild populations.
5. Prohibit the use of hatchery-produced (cultured) Sea Cucumber as brood stock due to the increased risks of genetic drift or selection in the hatchery production.
6. Restrict movement of Sea Cucumber brood stock, seed and juveniles to within Shellfish Transfer Zones, as described by the Introductions and Transfer Committee (Appendix 1), or smaller spatial scale. Use only brood stock local to the Zone to produce seed for out-planting to that Zone. Prohibit importing seed to a Zone other than the Zone of brood stock origin.
7. Establish quarantine protocols, for moving brood stock to and growing seed in out-of-Zone hatcheries; including standardized water treatment protocols for both influent and effluent water in and out of the hatchery to minimize risks of pathogen, parasite, and non-native species transfer between Zones.
8. If a disease or mass mortality event occurs in a hatchery, collect and submit representative samples of live and moribund (weak) Sea Cucumbers to the Aquatic Animal Health laboratory at PBS for analysis. Dead and decomposing specimens are rarely of any value and should not be sent. As more is learned of potential diseases that may affect wild or cultured populations, a screening program can be developed for specific pathogens, if appropriate.
9. Collect tissue samples of broodstock and progeny for each spawning to establish the size of the founding population and genetic variation within the offspring.
10. Implement of an effective reporting and traceability program for the by-catch harvest of wild animals to allow the incorporation of all sources of mortality into stock assessments.
11. Implement an accounting system to quantify the amount of natural-set Sea Cucumbers being collected for culture, and the magnitude of loss of Sea Cucumber juveniles due to de-fouling of all hanging aquaculture gear (not just the sites licensed for Sea Cucumbers), to allow an evaluation of wild juvenile mortality. The aquaculture industry is reliant on wild stock in this early stage of development and will continue to be so until hatcheries are successful in producing healthy stock for outplanting.
12. Track the amount of shoreline licensed for Sea Cucumber aquaculture to account for the potential mortality associated with aquaculture operations in wild stock assessments.

New knowledge is expected to be generated by the current ACRDP-funded research project ‘*Ecological interactions between benthic-ranched and wild California Sea Cucumbers*’. It is recommended that research in the following areas be conducted:

- Settlement and recruitment rates of wild juveniles on aquaculture gear and in the wild;
- Survival and growth of wild-settled juveniles on and off licensed areas;
- Age and size at maturity and fecundity of wild-settled individuals on and off licensed areas;
- Mortality rates of wild-settled individuals on culture gear after biofouling cleaning by various methods;
- Rate of natural drop off of wild-settled individuals from culture gear and fate of these individuals once they reach the sea floor;
- Survival and growth of hatchery-reared individuals in various types of containment systems;
- Effective tagging method; and

- Determination of the appropriate spatial scale for transfer zones, through the analysis of wild California Sea Cucumber DNA samples collected throughout the BC coast.

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Appendix 1 – Shellfish Transfer Zones

Shellfish already in natural waters may be susceptible to diseases or parasites found in that area. Not all disease and parasites are common to all areas and so movements of shellfish from one Zone to another presents risk of disease transmission, especially if a disease or parasite known in one area is not found in a receiving area. Similarly, there may be risks of adverse ecological and genetic effects from moving shellfish from one Zone to another. These issues are addressed by delineating Zones based on our current knowledge of shellfish diseases and parasites in B.C. waters, and in consideration of ecological and genetic concerns. Figure 1 shows the five Zones established for shellfish introductions and transfers in B.C. For consistency and clarity, the Zones are defined by Fisheries and Oceans, Canada (DFO) Statistical Fisheries Management Areas* as in Table 1 and Figure 1.

Table 1: Description of Shellfish Transfer Zones.

Zone	Name	Description
1	Haida Gwaii	Contiguous waters surrounding Haida Gwaii within Areas 101, 102 and 142, and Areas 1 and 2.
2	North & Central Coast	Contiguous waters of the mainland coast within Areas 103 to 107, inclusive, Areas 109 and 110, and Areas 3 to 10, inclusive.
3	Queen Charlotte Strait	Contiguous waters of Queen Charlotte and northern Johnstone Straits within Areas 111, 11 and 12.
4	Georgia Strait	Contiguous waters of southern Johnstone, Georgia and Juan de Fuca Straits within Areas 13 to 19-4, inclusive, and Area 28 and 29.
5	West Coast Vancouver Island	Contiguous waters of the west coast of Vancouver Island within Areas 121 to 127, inclusive, and Areas 19-1, 19-2 & 19-3, to 27, inclusive.

*Charts of DFO Statistical Fisheries Management Areas are available online.

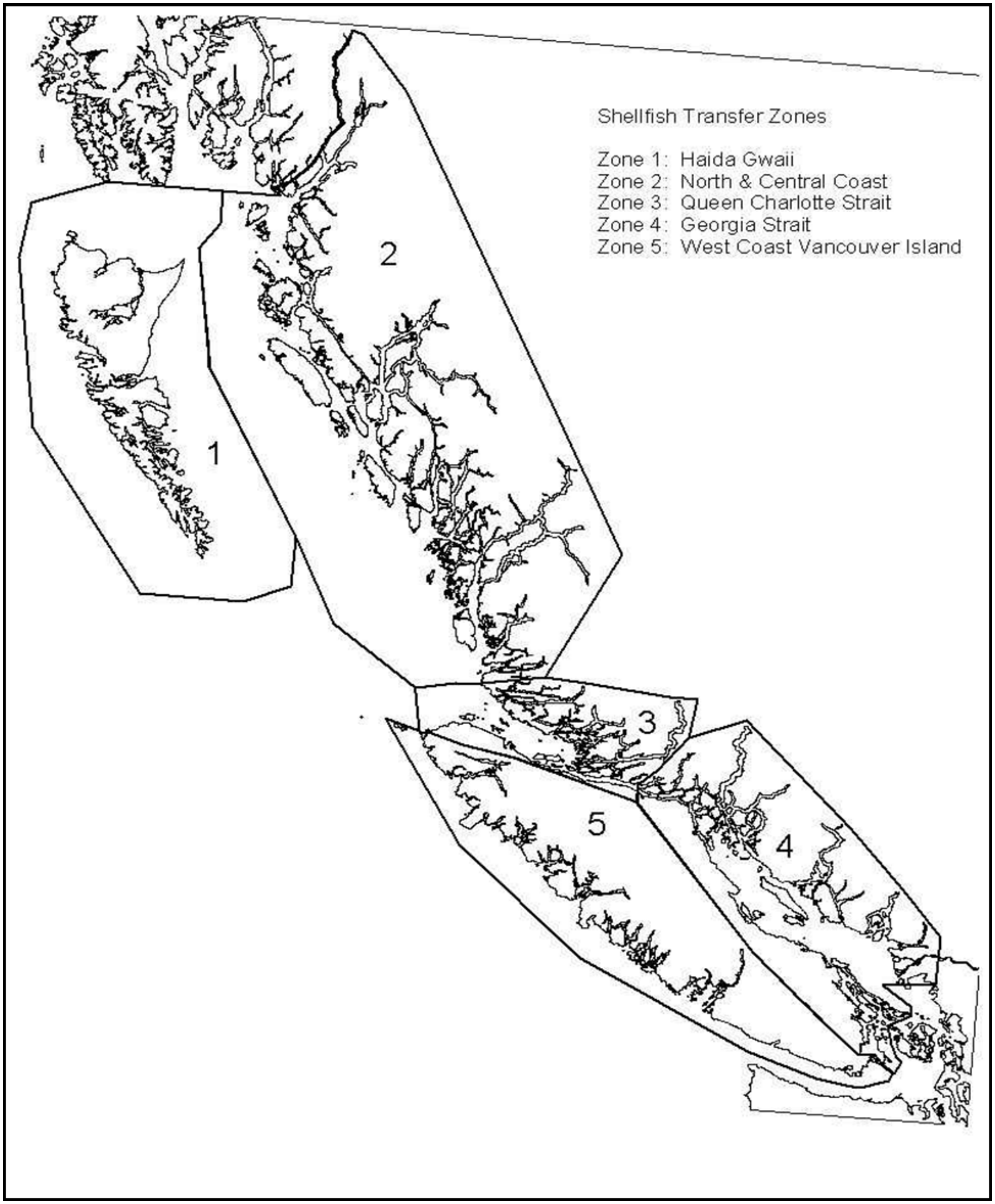

Figure 1. Shellfish Transfer Zones for British Columbia.

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