Fisheries and Oceans Canada — Pêches et Océans Canada
Science — Sciences

C S A S — Canadian Science Advisory Secretariat

S C C S — Secrétariat canadien de consultation scientifique

Research Document 2007/061

Document de recherche 2007/061

Not to be cited without
permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Recovery Potential Assessment for the northern abalone (*Haliotis kamtschatkana*) in Canada

Évaluation du potentiel pour le rétablissement de l'ormeau nordique (*Haliotis kamtschatkana*) au Canada

J. Lessard, A. Campbell, Z. Zhang, L. MacDougall, and S. Hankewich

Fisheries and Oceans Canada,
Stock Assessment Division,
Science Branch, Pacific Biological Station,
Nanaimo, B.C., V9T 6N7

ISSN 1499-3848 (Printed / Imprimé)

Canada

Table of Content

Abstract

This recovery potential assessment for the SARA-listed northern abalone includes a review of current status, population projections, and recommendations on permitting human-induced mortality and/or harm to abalone and their habitat. Recent surveys indicated northern abalone abundance was not recovering. Time series analyses of abalone survey data from areas free of sea otters in southeast Queen Charlotte Islands and Central Coast during 1978-2002 provided stock-recruitment relationships, recruitment trends and mortality estimates of > 0.20. Simulations indicated that abalone populations could continue to decline if mortality rates remain >0.20. Mortality rates of < 0.20 are required for abalone populations to recover.

Several human activities were considered that could potentially harm and cause direct mortality to abalone populations. In order of importance, these activities were: 1) directed fishing; 2) habitat alterations, including finfish aquaculture, log booms and log dumps, and dredging; 3) abalone aquaculture; 4) fisheries on food supplies (i.e. kelp harvest); 5) scientific research; and 6) rebuilding activities, including larvae or juveniles outplanting and adult aggregations. Collectively, harmful activities that can be permitted under SARA cause little mortality relative to poaching or sea otter predation. No allowable direct mortality is recommended.

Résumé

Ce document présente l'évaluation du potentiel pour le rétablissement de l'ormeau nordique, une espèce en voie de disparition, incluant la situation courante de l'espèce, des projections de populations futures et des recommandations pour permettre les activités qui pourraient tuer ou nuire aux ormeaux ou leurs habitat. Des échantillonnages récents ont démontré que l'abondance des ormeaux ne se rétablit pas. Les analyses de deux séries chronologiques d'échantillonnages, entre 1978-2002, dans des aires où les loutres de mer étaient absentes ont fourni des courbes de stock-recrutement, des projections de recrutement et des estimés de taux de mortalité de >0.20. Les simulations ont indiqué que les populations d'ormeaux pourraient continuer à diminuer si les taux de mortalité demeurent >0.20. Des taux de mortalité <0.20 sont requis pour rétablir les populations d'ormeaux.

Plusieurs activités humaines qui pourraient potentiellement nuire et causer la mortalité directe d'ormeaux ont été considérées. Par ordre d'importance, ces activités étaient : 1) pêche dirigée; 2) changements de l'habitat, y compris l'aquaculture de poisson, l'entreposage et les dépotoirs de billots de bois, et le dragage ; 3) aquaculture d'ormeau ; 4) pêche sur les sources alimentaires (c.-à-d. moisson de varech) ; 5) recherche scientifique ; et 6) les activités de rétablissement de l'ormeau, y compris l'ensemencement de larves ou de juvéniles et les concentrations d'adulte. Collectivement, les activités humaines qui pourraient potentiellement nuire et/ou tuer les ormeaux, qui peuvent être autorisées par la loi pour les espèces en péril, causent peu de mortalité comparativement à la mortalité causée par la prédation des loutres de mer et/ou du braconnage. Aucune mortalité directe n'est recommandée.

Introduction

The northern abalone (*Haliotis kamtschatkana*), a patchily distributed marine mollusc, has declined in numbers and distribution in surveyed areas of British Columbia (BC) as documented by regular surveys since the late 1970s. In response to observations of population declines, all abalone[1] fisheries (commercial, recreational and aboriginal) were closed in BC at the end of 1990. Despite the harvest closure, abalone numbers remained low and by April 1999, *H. kamtschatkana* was assigned a *threatened* status in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Jamieson 2001). This status was reconfirmed by COSEWIC in May 2000 (Campbell 2000). In June 2003, northern abalone was legally listed and protected as threatened under the Species at Risk Act (SARA). A recovery team was formed in November 2001 and prepared a 'National Recovery Strategy for Northern Abalone in Canada' (Abalone Recovery Team 2002). Following the completion of the recovery strategy, an action plan was drafted and is awaiting approval by the Minister. Both documents are available on the internet:

www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/default_e.htm

Recovery strategies identify what needs to be done to stop or reverse the decline of a species. The abalone recovery strategy's short-term goal is to halt the decline of the wild northern abalone population in BC in order to reduce the risk of the species becoming endangered (Abalone Recovery Team 2002). Over the long-term, the goal is to increase numbers and densities to self-sustaining levels in each biogeographic zone of BC in order to remove the species from the threatened status. The goal of increasing northern abalone to sustainable levels can be expected to take several decades. The measurable short-term objectives over the next 5 years are to ensure that mean densities of large adult (≥100 mm shell length (SL)) abalone do not decline below $0.1/m^2$ at surveyed index sites and that the percentage of surveyed index sites with large adult abalone does not decline below 40%. From the most recent surveys the mean densities of large abalone (≥100mm SL) were only $0.04/m^2$ in Queen Charlotte Islands (Haida Gwaii, QCI) in 2002 and $0.02/m^2$ on the north and central mainland coast (CC) in 2006 (Fig. 2), well below the short-term recovery objective of maintaining densities at or above $0.1/m^2$. The percentage of sites with large abalone was also below the short-term recovery target of 40% (Fig. 3). The short-term objectives of the recovery strategy have not been achieved and the abalone populations continue to decline or oscillate at low levels.

Northern abalone was the first species for which Fisheries and Oceans Canada (DFO), Pacific Region, prepared a recovery strategy, prior to the implementation of the SARA. Although recovery of abalone in BC was deemed feasible, recovery targets (sustainable levels; see above) were not defined and no assessment of potential harm to abalone population or their habitat were included in the recovery strategy. The objectives of this paper were to (1) assess the recovery potential and population status of abalone in BC and (2) review and assess the human activities that may harm abalone in BC and could be permitted under SARA section 73 or allowed under section 83. The request for a PSARC Working Paper is in Appendix 4.

---

[1] "Abalone" refers to northern abalone in this paper unless otherwise stated.

This document follows the ‘Allowable Harm Assessment’ (AHA) framework defined at a national workshop in 2004 (DFO 2004c). The AHA framework requires that the recovery feasibility be determined before any harms from human activities can be assessed, as such, the framework also includes a recovery potential assessment (Phase 1, see below). The framework to assess harms to a species at risk that could be permitted under SARA includes a number of steps divided into three phases. The first phase assesses whether recovery of abalone is feasible if human activities which affect the species were to continue. The second phase reviews and assesses the important human activities and conditions within which they must operate if recovery is to be feasible. Finally, the third phase develops the specific options and recommendations considering all the activities assessed, consistent with the provision of section 73 of SARA. Two sections, or steps, have been added into the framework: (1) a biology section reviewing the elements of abalone biology and ecology necessary for understanding the impacts of the different human-induced activities reviewed and assessed, and (2) a review and assessment of sources of mortality of abalone populations that cannot be permitted under section 73 of SARA, but that are so important that they cannot be ignored when considering recovery (Step 4.5). For the sake of brevity and ease of reading, the steps of Phase 3 have been removed as alternative methods (Step 9), mitigation measures (Step 10), science advice discussion (Step 11), and recommended options (Step 12) are included for each potential harm when they are assessed under Steps 6&7. Phase 3 summarizes the discussions of Phases 1 and 2 and lays out the recommendations in the usual PSARC format.

Summary biology and ecology of northern abalone

The biology of northern abalone was reviewed by Sloan and Breen (1988). In summary, northern abalone range from northern Alaska to Baja California in patchy distributions on exposed and semi-exposed areas from low intertidal to subtidal depths; most abalone off the coast of BC are found at depths shallower than 10m. Juvenile northern abalone (10-70 mm SL) are found under and on exposed areas of rocks, whereas the majority of adults (>70 mm SL) are found on exposed rock surfaces. As the juveniles develop to maturity, their diet changes from benthic diatoms and micro-algae to drift macro-algae. Abalone become sexually mature at about 50mm SL and all abalone are mature at 70mm SL (Campbell et al. 1992). Sea urchins and adult abalone have been shown to use the same habitats and may compete for algal food. Abalone predators include sea otters, some sea stars, octopus, crabs and fish.

Abalone growth can vary considerably between areas depending on the extent of exposure to wave action and availability and quality of food. In BC, estimates of the age at which abalone reach 50 mm SL are 2 to 5 years old and 100 mm SL are between 6 to 9 years (or more). Growth of adults tends to be stunted in highly exposed outer coastal areas due to reduced opportunities for abalone to catch, and feed, on drift algae in strong wave action and water currents. Abalone growth is more rapid in moderately exposed areas with giant kelp, *Macrocystis integrifolia*, or bull kelp, *Nereocystis luetkeana*, kelp forests than at highly exposed areas with *Pterygophora californica* kelp forests (Sloan and Breen 1988). Breen (1980) speculated that ages of 50 years or more were not improbable based on shell appearances and extrapolation from other invertebrate species. However, longevity of 15-20 years for northern abalone seem more appropriate based on age determined by spire growth rings (Shepherd et al. 2000) and observed sizes taken with growth curves (Quayle 1971; Sloan and Breen 1988).

Northern abalone spawn synchronously, with groups of males and females in close vicinity to each other in shallow waters broadcasting their gametes into the water column (Breen and Adkins 1980b). These aggregations are believed to enhance reproductive success in many abalone species by increasing the chance of fertilization (Sloan and Breen 1988; Shepherd and Brown 1993; McShane 1995a, 1995b; Shepherd and Partington 1995; Babcock and Keesing 1999; Dowling et al. 2004). Recent studies on several abalone species (McShane 1995a, 1995b; Shepherd and Partington 1995; Babcock and Keesing 1999; Dowling et al. 2004) and sea urchins (Levitan et al. 1992, Levitan and Sewell 1998) have pointed to reduced fertilization success caused by dilution of gametes through reduced adult spawner densities.

The planktonic phase of the northern abalone is short and temperature dependent (10-14 days at 14-10ºC) (Sloan and Breen 1988; Pearce et al. 2003). Since larvae of abalone species in general are non-feeding and are poor swimmers, many authors have suggested that larval dispersal is minimal and that recruitment is from local reproductive populations (Shepherd and Brown 1993; Tegner 1993; Tegner and Butler 1985; Prince et al. 1987; McShane et al. 1988; McShane 1992, 1995a, 1995b). Nevertheless, larval dispersal probably still occurs as genetic studies have found high genetic variation indicating gene flow over large areas with little population subdivision in several abalone species, including northern abalone (Brown 1991; Brown and Murray 1992; Shepherd and Brown 1993; Burton and Tegner 2000; Withler et al. 2003).

Stock definition of northern abalone has been considered, in the fisheries management context, as an abalone population within arbitrarily chosen geographic or management areas. Consequently most of the stock assessment surveys of abalone in BC have been on a broad geographic scale. Currently, 5 biogeographic zones are recognized to recover abalone (Abalone Recovery Team 2002): Queen Charlotte Islands, north and central mainland coast, Queen Charlotte and Johnstone Straits, Georgia Strait, and west coast of Vancouver Island. Evidence from recent studies have suggested that some abalone species may be made up of many populations in which stock recruitment relations may occur in small geographic areas (on a scale of hundreds of metres to several kilometres) based on gene exchange (Brown 1991; Brown and Murray 1992) and larval exchange (Tegner and Butler 1985; Prince et al. 1987; McShane et al. 1988). Shepherd and Brown (1993) suggested that an abalone stock be defined as a metapopulation made of several local discrete populations that have limited larval interchange. This stock definition allows for managing local abalone populations that may have variable demographic processes.

Few studies have shown strong stock recruitment relationships and the requirement of maintaining high adult abalone densities to ensure sufficient recruitment. Shepherd and Partington (1995) showed that there was a critical stock density threshold ($0.15/m^2$) for the *H. laevigata* in Waterloo Bay, South Australia, below which the risk of recruitment failure was high. Shepherd and Brown (1993) found that a "minimum viable population" of more than 800 individuals of *H. laevigata* was required; anything less at West Island caused recruitment failure. Shepherd and Baker (1998) suggested that recruitment to an abalone fishery could be relatively poorer and more variable in small than in large abalone populations, in which case small populations would need to conserve relatively more egg production to prevent depletion. These studies supported the influence of the Allee effect or depensation (Allee et al. 1949) in which low abalone densities and aggregations reduced reproductive success due to low fertilisation of gametes.

Campbell et al. (1992) reported fecundity of 156,985 eggs for a 57 mm SL abalone and of 11.56 million eggs in a 139 mm SL female. The largest female, 144 mm SL, carried 11.31 million eggs. From cumulative size frequency data of abalone surveyed off eastern Moresby Island during June 1990 (Thomas et al., 1990), Campbell et al. (1992) estimated that 50% of the total potential eggs could be produced by the mature females < 100 mm SL which constituted 80% of the total population surveyed. The remaining 20% of mature females in the 100-152 mm SL size group could produce about 50% of the total potential egg production. They concluded that large females are potentially important in contributing eggs to the total potential egg production.

Phase 1

Step 1: What is the present/recent species trend?

Since 1978, fishery independent surveys provided a time series through sampling abalone densities and size frequencies from QCI and the Central Coast of BC (CC), every 3–5 years (Fig. 1) (Adkins and Stefanson 1979; Atkins et al. 2004; Boutillier et al. 1984, 1985; Breen and Adkins 1979, 1980a, 1981; Breen et al. 1978b, 1982; Campbell et al. 1998, 2000a; Carolsfeld et al. 1988; DFO 2004a; Farlinger and Bates 1986; Farlinger et al. 1991; Lessard et al. 2007; Thomas and Campbell 1996; Thomas et al. 1990; Winther et al. 1995; and unpublished data for 2006 survey). In the early years (1978-1983), the surveyed sites were chosen because of harvestable commercial abalone abundances. The general survey method, by consistently using the standard 16 one m^2 quadrat survey method developed by Breen and Adkins (1979) at indicator sites (commonly known as the 'Breen' method), provided a time series of abalone abundance indices in the QCI and CC. Although there were a few published surveys of southern BC (Quayle 1971; Breen et al. 1978a; Adkins 1996; Wallace 1999; Atkins and Lessard 2004; Davies et al. 2006) they did not provide the extended coverage and the time series of the surveys in the northern half of BC. Most surveys were conducted in northern BC where historically the bulk of BC commercial abalone harvest occurred and abalone were considered most abundant (Sloan and Breen 1988). Consequently, the results from surveys at index sites in northern BC have been used by DFO, and others, notably COSEWIC, to make management decisions. (N.B.: The 2006 CC survey densities are presented, but should be considered preliminary as the survey report is in preparation and analyses are pending; J. Lessard, DFO, Nanaimo; pers. comm.).

The mean total abalone density[2] at comparable index sites declined from 2.40 to 0.40 abalone/m^2 for CC, during 1978-2006, and from 2.22 to 0.34 abalone/m^2 for QCI during 1978-2002 (Fig. 1). During the same periods, the mean large (≥100 mm SL) density decreased from 1.10 to 0.02 abalone/m^2 for CC and from 0.36 to 0.04 for QCI (Fig. 2). While there were significant declines of total densities with the previous surveys in both QCI 2002 and CC 2001, proportionally, the densities for large and mature abalone decreased more rapidly than that for small individuals (Atkins et al. 2004; Lessard et al. 2007). The mean size of abalone surveyed significantly dropped from 76.4 mm SL in 1998 to 67.0 mm SL in 2002 in QCI and from 80.7 mm SL in 1997 to 77.6 mm SL in 2001 in CC. The larger decreases in large and mature abalone densities as well as the decline in mean SL suggest size-selective fishing (poaching) mortality. Sea otters

[2] unless otherwise stated, all densities are of emergent/exposed abalone

were only present in a small portion of the CC surveyed areas (Nichol et al. 2005) and therefore, sea otter predation could not explain these reductions in density and mean size estimates.

Other surveys using different sampling designs also confirmed the low densities of abalone found by the index surveys in the same areas (Lucas et al. 1999; Cripps and Campbell 1998; Campbell and Cripps 1998; Lessard et al. 2002; Jones et al. 2003). The similarity in abalone density between new random sites and index sites indicated that the mean densities from all index sites were reasonably representative of adult abalone sampled in areas of CC in 1997 and QCI in 1998 (Lucas et al. 1999; Cripps and Campbell 1998; Campbell and Cripps 1998).

New index site surveys were initiated on the west coast of Vancouver Island in 2003 (WCVI) (Atkins et al. 2004) and in Queen Charlotte and Johnstone Straits in 2004 (Davies et al. 2006). The mean total density estimates were 0.06 abalone/m^2 in Queen Charlotte Strait and 0.02 abalone/m^2 in Johnstone Strait. Previous surveys done in a particular location in Johnstone Strait indicated high abalone density, up to 10 abalone/m^2 based on timed-swims in 1977 (Breen et al. 1978a), and 1.13 abalone/m^2 from a 1986 using the Breen survey method (Adkins, 1996). This particular location was the only place in Johnstone Strait where divers surveyed any abalone at all in 2004, save one individual at another site. Harvest logs confirm there were commercially harvestable numbers in PFMA 12 (Harbo 1997), but a survey by Breen et al (1978a) suggested that the fishery was largely confined to the north of Port Hardy, where densities were higher. In Queen Charlotte Strait in 1977, Breen et al. (1978a) visually estimated abalone densities to be generally low, 1/m^2 or less and noted a scarcity of juveniles. Although not directly comparable due to differences in survey designs, abalone densities in Queen Charlotte Strait have certainly decreased since 1977. Abalone densities in the Queen Charlotte and Johnstone Straits were at levels where the likelihood of recruitment failure is high (Shepherd and Brown 1993, Shepherd and Partington 1995; Babcock and Keesing, 1999; Campbell 2000).

On north west side of WCVI (north of Brooks Peninsula), the mean total density was 0.09 abalone/m^2 from all sites sampled, but 0.21 abalone/m^2 from sites in Quatsino Sound where more sheltered abalone habitat was present (Atkins and Lessard 2004). Sea otters, *Enhydra lutris*, have inhabited the surveyed area of WCVI since 1989 and more specifically since 1991 in Quatsino Sound (Watson et al. 1997). Even sampling only exposed abalone during 2003 were abalone present in areas where otters were established at higher abalone densities than that estimated by Watson (1993) in areas with sea otters. This may be the result of the relatively low densities which make abalone a scarce food resource for sea otters and are therefore not selected as sea otters often exploit seasonally abundant food resources (Watson et al. 1997). No other abalone surveys exist for the area surveyed in 2003; therefore trends for this area cannot be assessed.

A new index sites survey was planned for Georgia Strait in 2005, but because of budget constraints and other emerging priorities, only a small portion on the southern tip of Vancouver Island was surveyed in February 2005 (J. Lessard, unpublished data). Only 3 individual abalone were found at two (11%) of the 19 sites surveyed. The mean density for all sites surveyed was 0.0098 abalone/m^2. This estimate was drastically lower than density estimates from two previous surveys on the south coast; one in 1982 in PFMA 19, 0.73 abalone/m^2, and one in 1985 in PFMA 20, 1.15 abalone/m^2 (Adkins 1996). Sampling methodology in the 1982/85 surveys used preliminary visual estimates of abalone density, and the Breen method was only applied to sites where density was estimated to be >0.5 abalone/m^2. This would have resulted in higher mean density estimates for both Adkins (1996) surveys than if a random sampling method had been employed. Nevertheless, even assuming overall densities of half of the estimates of 1982/85 (0.47 abalone/m^2), the population of abalone in these areas has declined by more than 97% since the mid-80's. Due to access restrictions enforced by a prison, the waters around William's Head have been a marine reserve since 1958 (Wallace 1999). During a 1996/97 survey divers found 211 abalone in 275 minutes of diving (0.77 abalone/min) at this prison site. At 4 sites surveyed around Williams Head in 2005 (J. Lessard unpublished data), only one abalone was measured. Although a few more were observed around the quadrats, the abalone population around Williams Head was disappearing. This large decrease could be a result of poaching, but at this particular location because of the security, the most likely reason is simply that the large abalone found at the previous surveys have died and there has been no, or little, recruitment. The sizes of the three sampled abalone during the 2005 survey were 141mm, 135mm, and 135mm SL, well above the historical size limit of 100mm SL in place during the former fishery. The results from the 2005 survey were similar to surveys conducted in the San Juan Islands by Washington Department of Fish & Wildlife (D. Rothaus, WDFW; pers. comm.). Despite the fisheries closure, clearly the abalone population on the south coast has continued to decline and may have reached critical levels.

Step 2: What is the present/recent status?

From the most recent surveys, the mean densities of large adult abalone (≥100mm in SL) were only 0.04/m^2 in Queen Charlotte Islands (Haida Gwaii, QCI) in 2002 and 0.02/m^2 on the north and central mainland coast (CC) in 2006 (Fig. 2), well below the short-term recovery objective of maintaining densities at or above 0.1/m^2 (see Introduction). The percentage of sites with large abalone was also below the short-term recovery target of 40% (Fig. 3). Other surveys in other parts of BC show even lower densities (see above).

The short-term objectives of the recovery strategy (Abalone Recovery Team 2002) have not been achieved and abalone populations continue to decline or oscillate at low levels. Indeed the prospect of further precipitous abalone population declines must be considered a possible reality with the continued illegal harvest (poaching) by humans and the continued sea otter population growth and spread in BC (see below).

Steps 3 & 4: What is the expected target and time frame for recovery?

The short-term goals of the recovery strategy dealt with large abalone as these individuals have the most reproduction potential and if any future fisheries were to be considered, the portion of the abalone populations that would be exploited would probably be over 100 mm SL. At the time of writing, short-term objectives were set to observe if abalone population continued to decline, but no recovery targets were set. The short-term recovery objective of 0.1 large abalone/m^2 was chosen as a reference point to measure declines or growth of the abalone populations comparatively from the time the fisheries were closed. Furthermore, the long-term recovery targets will have to be based on smaller size classes in areas where sea otters are present and may be partly based on these larger abalone where sea otter population expansion is not expected in the next 10-20 years. Restoration of abalone populations to the levels seen in the late 1970s will not be possible in areas affected by the continuing expansion of sea otter populations. Figure 5 shows the density estimates of large (≥100mm SL) and mature (≥70mm SL) abalone from all index sites surveys in QCI and CC. In general, the trends in both mature and large abalone densities were similar. Around the time of the closure, the mature density estimates were 0.27 and 0.41 mature abalone/m^2 in QCI and CC, respectively.

It is instructive to use simple generic models to inform recovery goals for endangered species. Such a model was developed in order to determine recovery targets and time frame of abalone recovery. The simulation model and its various components are described in Appendix 1. The model is derived from survey time series data of >20 years in 2 geographic areas briefly described in Step 1 and more explicitly in Appendix 1. The model is based on the best available data in BC and comparison of simulated and observed densities of exposed abalone showed that the majority of observed densities fell within 90% confidence intervals of the simulated values (see Fig. 4-7 in Appendix 1). For these reasons, we consider the model reasonable and use it to derive recovery targets. However, as the surveys were completed in areas without sea otters, the recovery targets can not be set for areas currently or future occupied by sea otters.

1. Recovery targets

We propose recovery targets with a two phase approach using short term and long term time horizons. Measurable targets, using standard surveys of abalone, should include: (1) annual mortality estimates; (2) density estimates of emergent or "exposed" reproductive broodstock ($\geq$70 mm SL); and (3) frequency of patch sizes of abalone. The chosen recovery targets are listed for both the short- and long-term. Each measurable target is then discussed. As discussed earlier and in Appendix 1, abundance of immature abalone (<70 mm SL) is difficult to measure and study. If better methods are developed to estimate immature densities, recovery targets should include a measure of juvenile abalone abundance.

- Short term

The measurable short-term objectives over the next 10 years are to (1) reduce annual estimated mortality rates to <0.20, (2) ensure that mean densities of mature ($\geq$70 mm SL) abalone increase to $\geq$0.32/m^2 at surveyed index sites (twice the current densities in 2001 CC and 2002 QCI) and (3) increase the percent of surveyed quadrats with abalone to >40% (index sites surveys).

- Long term

The measurable long-term objective for the next 30 years are to (1) reduce and maintain annual estimated mortality rate to $\leq$0.15, (2) ensure that mean densities of mature ($\geq$70 mm SL) abalone increase to $\geq$0.5/m^2 at surveyed index sites and (3) increase the percent of surveyed quadrats with >1 mature abalone to >20% (index sites surveys).

2. Mortality rates

For adult abalone (different size fraction depending on method, see Appendix 1), mean mortality rates (Z) estimated in areas without sea otters were 0.23±0.04SE and 0.29±0.05SE for QCI and 0.21±0.06SE and 0.36±0.07SE for CC (Table 2 in Appendix 1). The higher Z estimates were probably more accurate for both QCI and CC as more of the survey-derived density estimates fell within the confidence limits of the model simulations (Fig. 4-7 in Appendix 1).

Simulation model predictions indicate that should annual mortality rates remain higher than 0.20, abalone populations will continue to decline (Fig. 8, 9 and 11 in Appendix 1). Indeed, in areas with sea otter presence, mean annual mortality values would be expected to be considerably higher than 0.20 (e.g., >0.35) and consequently abalone densities would decline at a more rapid rate with a possible earlier projection of critical densities (here set at 0.001) which would be considered un-recoverable. For example, with a Z=1.0, abalone can be expected to be below 0.001 abalone/m^2 in 25 years, and with Z=0.26 abalone would reach critical densities in >300 years (Fig. 14 in Appendix 1). Decreasing mortality rates is essential to the recovery of abalone in BC and should be a short-term priority.

3. Mean densities of mature (≥70 mm SL) abalone

The slope of the stock-recruitment relationship decreases around 0.2 kg/m^2 spawning biomass which correspond to about 1 spawner/m^2 (1 mature abalone ≥70mm SL/m^2) (Fig. 2-3 in Appendix 1). As the slope decreases, an increase in spawning biomass does not correspond to a comparable increase in the number of recruits and therefore the benefit of further increasing the number of spawners decreases. The majority of the survey data are below this level (Fig. 5).

The recovery target for delisting could be set at a mean of 1 spawner (mature)/m^2 at index sites surveys in the CC and QCI as this is the best available information we have. At a local scale (e.g., site level), a less conservative target could be set at half of this level to allow for potential conditional small harvest (see activity 1 under Steps 6-7). The time frame to recover abalone at the 1 mature abalone/m^2 level is not realizable within 50 years with the current mortality rates (Fig. 8-13 in Appendix 1). The mortality rate would have to decrease to at least 0.15 to recover abalone to the 1 mature/m^2 level within 70 years (Fig. 12-13 in Appendix 1 and assuming mature abalone densities of 0.15 in QCI in 2002 and 0.17 in CC in 2001). However, doubling the current mature density estimates in 10 years could be possible if mortality rates were lowered (i.e., without illegal harvest and/or sea otter predation) (Fig. 12-13 in Appendix 1).

4. Patch size

The size and distribution of abalone populations required for effective reproduction and subsequent sufficient recruitment are unknown. Current knowledge of abalone, in general, suggests that there needs to be sufficient densities within patches of large mature abalone close enough together to successfully spawn and produce viable offspring (see biology section). Figure 4 shows the proportion of quadrats surveyed with different counts of abalone. The proportion of quadrats with no abalone (zero counts) was around 80% in the latest survey in QCI and CC. Although patch size is not directly measured in these surveys, the frequency of quadrats with small counts is an indication that patch size and frequency were decreasing. As the number of abalone close together is important for fertilization success (see biology section), the relationship between patch size and the proportion of quadrat with different abalone counts needs to be established. If no relationship can be determined, patch size should be measured directly in future surveys. In the mean time, abalone counts per quadrat (1 m^2) could be used as a surrogate measure of patch size and frequency. An increase of 40% of total quadrats surveyed with abalone would effectively double the CC 2001 and QCI 2002 observations. Ideally, however, aggregations of reproducing abalone are needed to recover the populations and therefore an increase in the patch size and frequency of mature abalone should be the long-term goal.

Step 4.5: Important sources of mortality

This step is an addition to the framework proposed in DFO (2004c). The causes of mortality for which we cannot issue a permit under Section 73 of SARA are so important that they cannot be ignored when considering abalone recovery. In addition, without proper perspective in the different causes of mortality to abalone populations, the harm caused by the activities described in Steps 6-7 can seem considerable when in fact the aggregated mortality of these activities (those that can be permitted under Section 73 of SARA) is small compared to poaching and sea otter predation.

Watson (2000) suggested that the effects of sea otters and human harvesters have on abalone populations differ in several aspects. Sea otters have no regard for size limits and other management measures, but as abalone become rare, sea otters are energetically constrained and switch to alternate prey (Wild and Ames 1974; Ostfeld 1982). In contrast, as the abundance of abalone declines, abalone becomes more valuable, making it worthwhile to pursue a rare species for human harvesters. Furthermore human harvesters using specially designed tools have the ability to remove abalone from areas where sea otters cannot. The combination of sea otter predation and human harvest may prove too much for many abalone populations (Watson 2000). These two sources of mortality to abalone populations are discussed below.

1. Illegal harvest or poaching

Illegal harvest or poaching of abalone is considered an important source of abalone mortality (Jubinville 2000). Campbell (1997) estimated F (instantaneous fishing mortality) to be at least 0.20 for south east QCI and from 0.14 to 0.70 in some areas in CC during the post-fishery closure (1993-96) period. The mortality rates (Z) calculated in Appendix 1, 0.21-0.36, are higher than natural mortality rates (M), 0.15-0.20, estimated by Breen (1986) for adult abalone population in areas closed to the commercial fishery. However, Z estimates are within the range, 0.21-0.41, Breen (1986) estimated for areas exposed to the commercial fishery. This indicates that illegal harvest was probably still ongoing and was a major source of mortality. Using the M estimates from Breen (1986), fishing mortality (F) after the fisheries closure can be estimated to be 0.06-0.26.

Recently, 1997 – 2006, approximately 30 abalone poaching convictions have been made. In some cases, multiple charges were laid and strict sentences meted out to repeat offenders. However, fishery officers suggest that poaching remains a major concern and estimate that only 10-20% of poaching activity is prosecuted (B. Hume, DFO Conservation and Protection, Campbell River; pers. comm.). There were also 14 reports of suspected poaching in 2004 and 23 in 2005. The majority of reports received were from northern BC (B. Hume; pers. comm.).

2. Sea otter predation

Sea otters are considered a threat in the abalone recovery strategy (Abalone Recovery Team 2002). The sea otter is a natural major carnivore of many invertebrates, including abalone, and as a consequence can have a significant effect on the nearshore coastal ecosystems of BC (Watson 2000). However, sea otter abundance and distribution has been drastically manipulated and controlled by humans for over a century. Midden remains indicated that prior to the arrival of Europeans, First Nations may have extirpated local populations of sea otters (Simenstad et al. 1978). A massive fur trade occurred from the mid-1700s until 1911 when sea otters were protected under the International Fur Seal Treaty. By that time few populations remained and the last sea otter in BC was shot in 1929 resulting in the extirpation of sea otters in BC. Subsequently the sea otter was reintroduced into BC in three separate translocations from Alaska between 1969 and 1972 and, with absence of exploitation, the populations have grown and continue to spread in BC (Watson et al. 1997; Nichol et al. 2005).

Studies have shown that abalone, in areas where sea otters are present, are restricted to crevices and other cryptic habitats where they are inaccessible or hidden from sea otters (Lowry and Pearse 1973; Cooper et al. 1977; Pollard 1992; Watson 1993, 2000). It is unclear whether sea urchins and abalone inhabit crevices as a direct result of sea otter predation or because the abundant supply of food (perhaps an indirect result of sea otter predation) reduced their foraging activity (Lowry and Pearse 1973). Abalone populations have been present at low stable abundances in sea otter areas in California (Cooper et al. 1977, Hines and Pearse 1982; Wendell 1994). In BC, abalone do co-exist in area with sea otters, but it is not known at this time if this will persist when sea otters' preferred food item, sea urchins, is depleted. Sea otters and abalone have co-existed in BC for millennia prior to the extermination of sea otters by humans in BC (Watson 2000). However, the exact mechanisms for this coexistence and the survival of abalone at low abundance in BC are not known. Ecosystems are clearly complex and are always changing in spatial and temporal scales and can develop counter intuitive population changes (Sinclair and Byrom 2006). Carter et al (2007), using sea urchins, have shown that the "sea otter-trophic cascade paradigm" is not applicable in all locations and habitat types. Many factors, such as environmental variability (e.g., storm frequency, climate change) and biological factors (e.g., disease, invertebrate predators and competitors, density dependent effects on growth, reproduction, and survival) may positively or negatively influence abalone density and abundance in an area. Although there are indications of the influence of local sea otter populations on nearshore ecosystems on a small scale (e.g. < 50 km shoreline) (Lowry and Pearse 1973, Cooper et al. 1977, Hines and Pearse 1982, Watson 1993; Wendell 1994), there is no clear understanding of the distribution profiles and influence of sea otter populations will have on the stock recruitment relationships of abalone and other predator species on a small (<50 km shoreline) or large scale (e.g., >50 km shoreline). In areas where abalone have been severely depleted by natural factors and or human poaching, subsequent sea otter predation may significantly accelerate the decline and contribute to the demise of abalone populations in many areas of BC.

Mortality of red abalone, *H. rufescens*, populations in California in areas occupied by sea otters has been estimated at 0.3-1.0 (Hines and Pearse 1982 cited in Shepherd and Breen 1992) and 1.3 (Deacon 1989 cited in Shepherd and Breen 1992). In BC, there are no estimates of predation mortality by sea otters. However, rough estimates of mortality were calculated from Watson (1993, 2000) study on the effect of sea otters (*Enhydra lutris*) on nearshore ecosystems. At a permanent site in Kyuquot Bay, the mean number of abalone was 0.97/m^2 in 1988, decreased to 0.36/m^2 the following year and was 0.22/m^2 in 1990 (Watson 1993). At that site, sea otters were first observed in November 1988 and foraged sporadically thereafter (Watson 1993). The abalone mortality rates were estimated to be 0.99 and 0.49. No legal fishery took place once sea otters had occupied the area (Harbo 1997). At the two control sites (without sea otter foraging), abalone densities fluctuated between 0.01-0.09/m^2 and 017.-0.27/m^2. These mortality rate estimates should be considered carefully as they do not include the number of sea otters in the area recently occupied nor do they distinguished between natural mortality and sea otter predation. Nevertheless, these estimates are similar to those of California.

The Sea Otter Recovery Team (2003) recognized that conflicts between shellfisheries as well as abalone recovery will increase as the sea otter population(s) continues to spread to new areas.

Throughout the sea otter range in the Pacific, there is mounting evidence that many shellfish fisheries can not co-exist in the presence of an established sea otter population (Sea Otter Recovery Team 2003). During the consultations on the sea otter recovery strategy, the shellfish industry and some First Nations expressed the view that sea otter numbers have rebounded sufficiently in some areas, and that sea otters should be managed to control their numbers in those areas. Sea otters have been referred to as 'keystone' predators (Soulé et al. 2003), and contribute to the structure of nearshore ecosystems, with both direct and indirect effects on other species at risk and their associated habitats. Most of what we know about abalone in BC is based on studying systems without sea otters. There is no evidence that sea otter will enhance abalone spawning success by concentrating abalone in refugial habitats (crevices, under rocks, etc.). Ecological studies of northern abalone need to be conducted in experimental areas with sea otter populations present and absent to determine if future management of sea otters is required in some areas given that sea otter populations continue to grow and spread which threaten to accelerate the decline of abalone populations in BC.

Phase 2

Step 5: What is the maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery?

Based on the best information available, including index site surveys time series and the derived model, mortality rate estimates were >0.20 in sea otter free areas of northern BC after the closure to all fisheries in 1990, which likely contributed to continuing abalone population low abundances. Model simulations predicted that with mortality rates >0.20, abalone populations would decline further. As abalone are not recovering, the maximum human-induced mortality should be near zero as an increase in mortality rate will further reduce the abalone populations in BC.

Steps 6 & 7: The major potential sources of mortality/harm and the amount of mortality/harm caused by each

At present, assigning estimated specific annual mortality rates due to each potential source or causative agent is difficult. However, we provide a qualitative relative estimate of direct and indirect mortality (with an estimated range of mortality rate (F) values) assigned to each potential source in Table 1 as follows: High = $F \geq 0.10$; Medium = $0.10 > F > 0.03$; Low = $F < 0.03$; Minimal = $F < 0.01$. Mortality causative agents can vary between small areas and large areas and between years. Clearly the cumulative effect of all the natural and human induced mortalities can be overwhelming to abalone populations. The potential mortality agents are listed below in order from the largest to the lowest estimated impact on abalone populations in BC. Unless stated, 'mortality' refers to mortality caused directly by the activity and harm refers to impacts of the activity that may lead to increase mortality (indirect mortality).

1. Directed fishing

Directed commercial and recreational fisheries will not be considered here as they are unlikely to be opened in the near or distant future. In addition, criteria to re-open the commercial fishery were already set in Campbell (1997). While abalone fisheries were opened, there was little known about the extent of First Nations and recreational harvesting, although the level was probably well below the commercial harvest (Sloan and Breen 1988).

Conservation takes precedence over First Nation harvest for food, social and ceremonial purposes. Given current mortality rates calculated from index sites time series, directed fisheries are not possible. On the other hand, education and community projects have had little effect to decrease illegal harvest because the benefits of conserving and enhancing the abalone resource are not seen and are even thought to be not realizable. The recovery is simply taking too long for most people to see a benefit in becoming involved. Prince et al. (1998) advocated Territorial User Rights Fisheries (TURF) for protecting abalone populations. A form of TURF management was recently implemented to reduce poaching in the heavily exploited gastropod *Concholepas* fishery in Chile (Castilla et al. 1998).

Several First Nation communities have been involved in abalone rebuilding projects in BC for several years. One possible action to increase stewardship would be to consider linking success in enhancement/rebuilding projects (e.g., juvenile outplanting) at specific sites by local First Nations with a small harvest of abalone for food, social, and ceremonial purposes under strict controls (e.g., within 1-2 days, with DFO enforcement personnel present on the grounds, etc.). The harvest would only occur if sufficient abalone densities are present at the site where rebuilding activities have been taking place The site would need to be monitored and have yearly surveys to determine success (e.g., above a certain abalone density threshold). Along with education, these small projects may increase the abalone population locally and give an incentive to protect this resource in their surrounding areas. Similar to requirements for the abalone aquaculture industry, a harvest could be considered with a requirement to contribute to abalone rehabilitation. As different methods of rebuilding may be used depending on the area (e.g., adult abalone aggregation in an area with sea otters may be counter productive to rehabilitation), decision rules will have to be project specific, but overarching decision rules on required abalone densities, minimum recovery work necessary, and monitoring requirements will have to be decided in consultation with First Nations and all stakeholders. The recovery targets given in Steps 3-4 can help set required densities at which a given site would be harvested after several years of rebuilding work.

At the present time, the mortality from directed (legal) fishery is zero. Future harvest, if approved after consultations and under set protocol, cannot be estimated at this time.

2. Habitat alterations

A protocol was developed in April 2004 to address the siting of proposed finfish aquaculture tenures and their impacts on abalone populations and their habitat. Portions of this protocol have been integrated into 'DFO Marine Fish Habitat Information Requirements (HIR) for Finfish Aquaculture Projects' (DFO 2005). The protocol, included in Appendix 2, has been revised as part of this AHA to include all works and developments in, on, or under the water proposed in areas of abalone habitat.

The construction of underwater pipes or cable placement, installation of pilings, or other developments may have similar impacts as dredging and may be of interest if they occur in areas that contain abalone populations. Similar to dredging projects, however, if a project is small and the impacts on abalone populations are localized the transfer of individuals out of the area to another suitable habitat may be feasible, according to the protocol described in Appendix 2.

- Finfish aquaculture

The impact of aquaculture on abalone has not been studied, except for a small experiment conducted in 2005-06 in the Broughton Group, Queen Charlotte Strait (Appendix 3). However, the effects of aquaculture on the benthic ecosystem in general have been reported, with an emphasis on soft sediment habitats. The nature of suspended solids, the rate at which they are released from the farm, water turnover time and sediment quality are key factors in determining the effects and impacts of eutrophication (Winsby et al. 1996; Black et al. 2001; Chamberlain et al. 2001; Nordvarg 2001). Environmental impacts from fish farms are similar to that found near other forms of organic pollution (sewage outflows, pulp mill effluent). Inputs which exceed the assimilative capacity of the benthic environment can result in increased nutrient levels; reduced oxygen concentration; lowered redox potentials; release of hydrogen sulphide, ammonium, and methane; and physical changes to the substrate (Winsby et al. 1996; Black et al. 2001). These changes can initiate successional changes in macrobenthic species diversity, abundance, and biomass, and continued inputs may result in reduced macrobenthic species richness and changes in community structure. Specifically, highly impacted areas directly under pens where waste accumulation is constant and substantial are characterized by few, if any, macroinvertebrate taxa (Winsby et al. 1996). This may be due to constant smothering or alterations in oxygen level.

The intensity and duration of aquaculture impacts are related to current and water depth, extent of the disturbance, length of time the aquaculture facility is in operation, size of the facility, feeding rates, and sediment particle size. Facilities that are located in areas of low current and shallow water will have a greater accumulation of sediment directly under the pens; however an area of higher current may transport the sediments and chemicals further from the facility. Uneaten feed particles have a higher capacity than digested materials to impact the environment in terms of energy content and degradation rate, although some reports suggest that feed losses are being reduced in net pen culture (Black et al. 2001).

Toxic effects from effluent sources, such as aquaculture facilities, may have varying degrees of impact depending on the invertebrate species and life stage. Haya et al. (2001) studied the effects of chemicals used in salmon farming on bivalve and lobster populations. They observed that late stage larvae and adult lobster were more susceptible to toxic effects from insecticides than earlier stage lobster larvae; however, there were no significant toxic effects on any of the bivalves included in the study. A study in California found that chemical effects on red abalone larvae in the laboratory may be analogous to processes occurring in the environment; zinc effects included abnormal larval shell development and reductions in successful metamorphosis (Hunt and Anderson 1989). The authors observed that toxin levels in southern California effluents have been found at concentrations higher than those used in the study, and declines in abalone abundance and growth rate have been observed near outfalls (Hunt and Anderson 1989).

An experiment in the Broughton Group in Queen Charlotte Strait showed that abalone at control sites grew significantly more in two months than abalone placed within the finfish aquaculture tenures (Appendix 3). The animals outplanted were in poor health; this might have exaggerated the differences between tenures and control sites. In Queen Charlotte Strait, abalone densities found at index sites (0.080 abalone/m^2) and random sites (0.024 abalone/m^2) were lower than densities in the immediate vicinity of finfish aquaculture sites (0.125 abalone/m^2), although this difference was not statistically significant (Davies et al. 2006). Surveyed sites at aquaculture tenures were not randomly selected, but were placed at the nearest good abalone habitat found by the pen-system which could have biased density estimates. Nonetheless, it appears that abalone can live in the vicinity of pen-systems as four out of seven tenures surveyed in Queen Charlotte Strait had abalone at the site. The tenures where abalone were found have been in operation since 1991-1995 (M. Ayranto, Pan Fish Canada Ltd, Campbell River, BC; pers. comm.) indicating that abalone can survive several years within salmon aquaculture tenures. Abalone were also naturally present at other tenure sites in the Broughton Group in the vicinity of the experiment summarized above (C. Blackman, Marine Harvest Canada, Campbell River, BC; pers. comm.).

Although there is no clear answer as to the impacts of finfish aquaculture on abalone populations, to be precautionary an impact on growth, at the minimum, should be assumed. A SARA permit is not required as it has been determined that the level of protection provided by the *Fisheries Act* is consistent with the level of protection required by section 58(1) of SARA. Therefore, when it has been determined that there is no harmful alteration, disruption or destruction of fish habitat (HADD) under section 35 of the *Fisheries Act*, there will not be any destruction of aquatic habitat under SARA (DFO 2004b). No direct mortality on abalone is expected from this activity as netpens are 10-15m deep and consequently have to be placed in deeper water than abalone preferred habitat. Harms on abalone populations will have to be assessed through the monitoring phase of 'Impact Assessment Protocol' (Appendix 2) and HADD will be authorized through the *Fisheries Act*, if need be. The mortality associated with this activity is expected to be low as long as the protocol outlined in Appendix 2 is followed.

- <u>Log booms and log dumps</u>

While there are no studies specifically directed at these structures and their effects on abalone, log handling and storage is known to result in shading, water quality degradation, and modifications to habitat. Bark and wood debris may smother clams, mussels seaweed, kelp and sea grasses, and bark coverage may persist in the area for decades (Hanson et al. 2003). Accumulation of bark can result in locally decreased epifauna richness and abundance (Jackson 1986; Kirkpatrick et al. 1998). Storage of log materials and the loss of bark can result in the release of soluble organic compounds, increasing the oxygen demand within the area of accumulation. Increased oxygen demand can create anaerobic zones where toxic sulphide compounds are generated, particularly in brackish or marine waters. Shading can affect marine plant growth, including kelp and seagrass beds (Hanson et al. 2003), which can reduce the amount of food and cover available to adult abalone (Tegner et al. 2001).

If abalone are present at a proposed log booms or log dump site considered for approval, they could be moved to a suitable location following the protocol outlined in Appendix 2.

The expected mortality from this activity is near zero if the 'Impact Assessment Protocol' (Appendix 2) is followed. A SARA permit will be required if abalone are to be moved.

- <u>Dredging</u>

Dredging can affect benthic and water column habitats by direct removal and burial of organisms, siltation effects, contaminant release and uptake, release of oxygen consuming substances, and alterations to hydrodynamic regimes and physical habitat. Physical factors including particle size, distribution, currents and compaction/stabilization processes can regulate recovery after dredging (Hanson et al. 2003). Recolonization can take up to 1-3 years in strong current areas, or as long as 10 years in lower current areas. Sensitive habitats may be damaged; dredging can physically destroy kelp and eelgrass beds, or modify current patterns and water circulation affecting vegetation and larval settlement. Disposal of dredged material results in varying degrees of change in physical, chemical and biological characteristics of the substrate (Hanson et al. 2003). Discharges can smother benthic organisms and force mobile animals to leave. Erosion, slumping or lateral displacement of the surrounding bottom of such deposits can affect the substrate beyond the dump site by changing or destroying benthic habitat. Suspended solids reduce light penetration which may affect kelp beds as well (Hanson et al. 2003).

In general, most dredging activities take place around rivers mouth or where sediments may accumulate due to wave action. As such abalone habitat is unlikely to be impacted, but the potential impacts should be kept in mind when habitat managers are considering this activity. If abalone are present in the proposed impacted zone, they could be moved to a suitable location following the protocol outlined in Appendix 2. The expected mortality from this activity is near zero. A SARA permit will be required if abalone are to be moved.

3. Abalone aquaculture

As part of the strategy to rehabilitate northern abalone in BC, initial attempts were to include development of aquaculture methodology for use in stock rebuilding initiatives (Abalone Recovery Team 2002). This required the removal of mature abalone from the wild from a number of areas to provide broodstock for seed production at aquaculture facilities throughout BC. A protocol, reviewed by PSARC, is already in place which has been used in the latest broodstock collections and a similar protocol was used for the earlier collections in 1999 to 2001 (Lessard et al. 2002).

Hatchery reared abalone that are not outplanted are sold to recoup costs and provide an economic incentive to the coastal community to support abalone recovery. Tracking protocols are in place to limit the avenues through which wild abalone may be “laundered” as cultured product. Provided current tracking protocols remain in place, no negative impact to the wild abalone population is expected.

Hatchery reared abalone may be used for scientific research as an alternative to the use of wild abalone and can provide important information to fill knowledge gaps identified in the abalone recovery strategy. Most recently, a study of diseases in hatchery reared abalone raised in local seawater was conducted (S. Bower, DFO, Nanaimo, pers. comm.).

At the time of writing, there is only one active abalone aquaculture facility located at the Bamfield Marine Science Centre and operated by the Bamfield Huu-ay-aht Community Abalone Project (BHCAP). There are abalone in two other aquaculture facilities, but they do not have an agreement with DFO to collect more broodstock. An agreement is in place between BHCAP and DFO outlining the required rebuilding work, amongst other conditions, necessary to justify broodstock collections. Although provisions are in place to return broodstock to the wild, the protocol assumes 100% mortality as a risk adverse approach. A survey is required in order to calculate the number of abalone that can be collected for broodstock that year. BHCAP requires about 100 or less abalone per year.

4. Fisheries on food supplies (i.e. kelp harvest)

Adult abalone populations are affected by the availability of drift kelp as a food source (Tegner et al. 2001). In particular, the collapse of red abalone populations in California have been attributed to a combination of warmer water temperatures, fishing induced declines in adult abalone density, and reduction of kelp densities due to El Nino related storm damage (Tegner et al. 2001). Ino (1968) reported that over-utilization of kelp contributed to the decline of abalone populations and the closure of abalone fisheries in some areas. The blacklip abalone (*H. ruber*) showed the strongest response to the removal of kelp canopy amongst common macroinvertebrate species in an Australian study; population numbers were reduced by half, likely due, in part, to increased predation of these individuals (Edgar et al. 2004).

The Ministry of Agriculture and Lands (MAL) is responsible for the management of the commercial harvest of marine plants in BC. A Licence to Harvest Marine Plants is required to undertake a commercial harvest of any marine plant, including harvest for the purposes of the commercial Spawn-on-Kelp (or Roe-on-Kelp) fishery. The licence stipulates the species, quota, method of harvest and area of harvest. At present, all harvest of marine plants in BC is conducted by hand. There are conditions stipulated on the licence about where a plant may be cut, what portion of the plant may be harvested, and, on occasion, a condition that only one plant in four may be harvested in a given area to ensure that the integrity of the bed is not affected. MAL guidelines stipulate that no more than 20% of the total biomass of a marine plant bed may be harvested. This is to ensure long term sustainability of the resource and to minimize the impact on habitat. Most harvest levels are set substantially below the 20% maximum harvest level.

In 2003, there were 69 licences issued to harvest marine plants. Over 250 tonnes of giant kelp (*Macrocystis integrifolia*), bull kelp (*Nereocystis luetkeana*), sea lettuce (*Ulva* spp.), bladderwrack (*Fucus gardneri*), sea asparagus (*Salicornia pacifica*, a vascular plant), and many other marine plants are commercially harvested and processed each year in BC (Ministry of Agriculture and Lands 2006).

The expected mortality or harm from this activity is unknown. Although, over-utilization of kelp and canopy removal have been shown to affect abalone populations (Ino 1968; Edgar et al. 2004), the harvest levels set by MAL are probably low enough to ensure that abalone are not at risk of starvation. As such, given the harvest level guidelines, mortality caused by this activity is probably low to near zero.

5. Scientific research

The majority of the scientific research currently ongoing involves non-destructive sampling. In recent years, because of the low abundance, destructive sampling has not been considered. Such sampling would give information on reproductive potential, metabolic condition, diets, and several diseases. Sex determination and an index of reproduction potential is possible without killing the individual, but this is not often done because of the increased diving time required.

The recent research has involved mostly underwater survey where disturbance is minimal. An individual abalone may be wedged between rocks and may have to be picked up underwater for a more accurate measurement. The sunflower star *Pycnopoda helianthoides* is used to elicit an escape response to dislodge abalone without injury. This technique is in every protocol in use to survey abalone in BC. Several research projects, generally involved in rebuilding pilots, have brought the abalone out of the water in order to affix a numbered tag. Abalone are kept in circulating salt water or submerged in cages as long as possible to minimize exposure to air during tagging. Increased mortality associated with tagging appears to be largely due to increased predation on stressed abalone by *P. helianthoides* and not as a result of increased injury from tagging, based on personal experience, video footage and recapture of tagged animals (J. Lessard, DFO Science, Nanaimo; B. Defrietas, Haida Fisheries Program, Queen Charlotte City; J. Harding, Kitasoo Fisheries Program, Klemtu).

Information gathered during pilot projects has made valuable contributions to knowledge gaps identified in the recovery strategy. Therefore, non-destructive sampling, such as surveys, should be allowed to continue without a SARA permit. However, projects involving tagging or moving abalone to a different site, because of the potential mortality associated with exposure to air, should submit a SARA permit application to ensure proper procedures are followed. Mortality expected from scientific research is minimal.

6. Rebuilding efforts

"The objective of 'rehabilitation', 'rebuilding' or 'enhancement' of abalone populations is to use a combination of methods to increase the depleted population size to a higher level of abundance and to increase population distribution by replacement of individuals in areas totally depleted of abalone patches" (Campbell et al. 2000b).

Campbell et al. (2000b) reviewed and made recommendations of most, if not all, rebuilding methods available. They described each method and its relative success elsewhere in the world and gave pros and cons for each. However, several impacts were not considered. Rebuilding efforts that could harm abalone comprise (1) outplanting/seeding of larvae or juveniles from a hatchery and (2) adult aggregations usually collected from nearby wild populations. Both benefit reproduction output by increasing densities in a specific area thereby increasing fertilization rates. Adult aggregation has a potentially short-term as well as long-term benefit and the larvae or juveniles will potentially benefit the population in the long-term when the individuals reach reproduction age/size. There are two main risks associated with rebuilding efforts (1) the possible spread of diseases and (2) the loss of genetic diversity.

Bower (2000) notes that comparatively little is known about northern abalone diseases and provides a literature review of available information. Bower (2000) classifies infectious diseases of abalone into three main categories. Category 1 identifies 6 pathogens, including *Labyrinthuloides haliotidis*, which decimated young cultured abalone in BC. Category 1 pathogens have been observed to cause severe disease in wild or cultured abalone; some pathogens have been reported to cause mass mortality in only one area but are known to be present worldwide. Category 2 includes pathogens such as nematode and trematode species that have been observed to cause infection but have not been linked to significant mortality or are infective only during a restrictive part of the life cycle. Category 3 includes organisms that can have serious impact under appropriate environmental conditions only. Transplantation of abalone from one area to another can extend the natural range of pathogens or introduce pathogens to different environmental conditions with unpredictable potential impact. Bower (2000) cautions that transplantation from infected areas is to be avoided, and transplant animals should be quarantined to ensure they are free of infection prior to introduction.

To safeguard genetic variability, Withler et al. (2001) recommended that the number of abalone broodstock used to produce larvae or juveniles for outplanting to the wild should be at least 50 and preferably 100, with equal number of males and females. For the re-introduction or enhancement of endangered species, it has been recommended that a minimum of 20-30 animals be used as a founding population (Ralls and Ballou 1992) and that animals be collected from several locations to provide adequate genetic diversity (Templeton 1990).

- Larvae and juvenile outplanting

Releasing hatchery reared abalone larvae has met with limited success, with most studies concluding that larval release is not suitable for large scale restocking (Roberts et al. 1999). Successes have been reported for many areas of the world; to date Asia is the largest producer of hatchery reared abalone and South Africa as the second largest producer (Troell et al. 2006). In both Asia and South Africa, abalone hatcheries produce abalone for market sale as well as seeding of kelp beds for stock enhancement or rehabilitation of overfished stocks (Simizu and Uchino 2004, Troell et al. 2006).

The disease risk is almost nil for larvae outplanting as the larvae do not come in contact with the adults potentially carrying the diseases and the duration of stay in the hatchery is short (2 weeks) (Pearce et al. 2003). A subsample of the juveniles to be outplanted can be tested prior to outplanting to determine if they are disease-free. All transfers of abalone to and from the wild are required to be permitted by the federal/provincial Introductions and Transfers committee (I&T) who will consider risk of disease resulting from the transfer. For SARA listed species, the I&T committee requires a SARA permit before an I&T permit is given. The harm associated with this activity is minimal if proper procedures are followed (i.e. I&T and SARA permits). Under the right conditions, outplanting can be successful and the benefits outweigh the risks.

- Adult aggregation

Moving and aggregating mature abalone to increase the local density and consequently their reproductive potential could help in their rehabilitation. Campbell et al. (2003) discussed the implications of transplanting abalone from 'poor' to 'good' habitats to increase survival, growth and reproductive potential, as a rebuilding technique for northern abalone in BC.

In the Broken Group Islands, a DFO-Parks Canada collaborative project is exploring methods and factors that improve abalone reproduction and recruitment by increasing adult densities and growth to increase reproductive success and capacity of normal and stunted 'surf' abalone. Preliminary results indicate that aggregation was successful in increasing densities of juvenile abalone at the experimental sites (J. Lessard, pers. comm.). Parks Canada, using night diving when small abalone come out of cryptic habitats, showed that <3 years old abalone were more abundant closer to one aggregation site (T. Tomascik, Parks Canada Agency, Vancouver; pers. comm.). In California, mature green abalone, *H. fulgens*, were collected from a site of abundance, tagged, and clustered in two sites where abalone populations had severely declined (Tegner and Butler 1985). Within the first year, the transplanted abalone showed signs of reproduction and were estimated to have a 10% natural mortality. In addition, large numbers of juveniles the following three years indicated an increase in recruitment in the transplanted areas. Abundance of the large tagged individuals declined significantly during the same time period, however, and lack of tagged shells suggested poaching was the major cause of mortality (Tegner 2000).

As aggregation requires taking abalone out of the water, a SARA permit application will be necessary. Disease testing requires destructive sampling and will not be allowed (see Scientific Research section under Steps 6-7), therefore collection sites should be within the same geographic region to avoid the spread of disease as well as long exposure to air while travelling.

Adult aggregations can successfully enhance reproductive output of local population; as such the benefits outweigh the risks. So far, ongoing rebuilding projects have occurred in parallel with Coast Watch, or similar, programs where surveillance is increased. The expected mortality from this activity is minimal.

7. Dismissed activities

- Military activities

  There are no known military activities that impact abalone.

- Bycatch

  Abalone are not a legal bycatch of any fishery.

- Detrimental impacts on habitats by fishing activities

  Fisheries for which there are habitat impacts take place deeper than abalone distribution.

- Ecotourism and recreation

  Except for poaching, presumably due to ignorance or blatant disregard, there are no impacts from these activities.

- Shipping, transport, and noise

  Abalone are not known to be affected by noise and they are not affected by shipping and transport.

Step 8: Aggregate of the total mortality/harm from human activities and contrast with model.

In general, little mortality is expected from legislated or permitted human activities. The direct and indirect causes of mortality are addressed through a published protocol for broodstock survey and collection and the protocol described in Appendix 2 for works and developments. A directed First Nations fishery is not considered at this time, at least until a protocol is in place which will require consultation and agreement between groups of minimum requirements for abalone densities, rebuilding work, monitoring requirements, and timing and enforcement of harvest. Harm may be expected from finfish aquaculture activity or other types of works and developments, but more information is needed and the protocol in Appendix 2 addresses this through a monitoring phase after approval.

Phase 3: Options

Summary and conclusions

The northern abalone is vulnerable to over-exploitation due to its patchy distribution, short larval period, slow growth, long life, and low or sporadic recruitment. Mature individuals also tend to accumulate in shallow water where they may be easy to access. Survey results at index sites in QCI and CC showed that population densities declined by >80% during the period of 1978-2002

(Atkins et al. 2004; Lessard et al. 2007). The short-term objectives of the recovery strategy (Abalone Recovery Team 2002) have not been achieved and abalone populations continue to decline or oscillate at low levels. The projected population trajectory does indicate that survival and recovery are in jeopardy, but not from the human activities described in Steps 6-7. The most probable causes are illegal harvest and the resulting low mature densities leading to poor recruitment. The continued expansion of sea otters will further accelerate the decline of abalone abundances.

Measurable targets, using standard surveys of abalone, should include: (1) annual mortality estimates; (2) density estimates of emergent or "exposed" reproductive broodstock ($\geq$70 mm SL); and (3) frequency of patch sizes of abalone. Both short-term (10 years) and long-term objectives are proposed for each of the measurable target.

The mortality caused by poaching and sea otter predation, where they are present, is large when compared to aggregated mortality of the activities described in Steps 6-7 (those that can be permitted under Section 73 of SARA). The mortality rates (Z) calculated in Appendix 1, 0.21-0.36, were higher than natural mortality rates. This indicates that illegal harvest was probably still ongoing and was a major source of mortality. Sea otter caused mortality rates have been estimated to be between 0.3 and 1.3. Literature indicates that in sea otter areas, initial abalone mortality rates are in excess of sustainability based on the current model. There are still knowledge gaps as to the long term implications on abalone due to ecosystem changes. Ecological and abalone population parameters need to be measured in areas without sea otters, in areas where sea otters have recently arrived and in areas where sea otters have been established for several years. As otters expand, it will be crucial to have this information if we are going to recover abalone. Halting the decline and increasing abalone abundance to sustainable levels as currently defined in the recovery strategy (Abalone Recovery Team 2002) will not be possible in areas occupied by sea otters.

Model simulations indicate that with mortality rates >0.20, abalone populations will decline further. As abalone are not recovering, the maximum human-induced mortality should be near zero as an increase in mortality rate will further reduce the abalone populations in BC.

We suggest that First Nations harvest be considered after a protocol is agreed upon in order to increase stewardship and help reduce poaching. The protocol development for First Nation harvest will require consultation and agreement between groups on minimum requirements for abalone densities, rebuilding work, monitoring protocol, timing of harvest and enforcement.

SARA permits will be required for broodstock collections, tagging as part of research, except in situ tagging, and movement of abalone as part of rebuilding efforts or approved works and developments as described in the protocol in Appendix 2. Scientific research and rebuilding projects are essential to the recovery of northern abalone. To minimize handling stress, SARA permit conditions, similar to those described in Appendix 2, should continue to be set. When appropriate, SARA permit conditions should also include an I&T permit requirement to consider risk of disease. Reports are required as a condition of the SARA permits, including reporting of mortality, in which case alternate measures can be devised.

Recommendations

1. The proposed measurable short-term objectives over the next 10 years are to (1) reduce annual estimated mortality rates to <0.20, (2) ensure that mean densities of mature ($\geq$70 mm SL) abalone increase to $\geq$0.32/m^2 at surveyed index sites (twice the current densities in 2001 CC and 2002 QCI) and (3) increase the proportion of quadrats with abalone at surveyed index sites to >40%.
2. The proposed measurable long-term objective for the next 30 years are to (1) reduce and maintain annual estimated mortality rate to $\leq$0.15, (2) ensure that mean densities of mature ($\geq$70 mm SL) abalone increase to $\geq$0.5/m^2 at surveyed index sites and (3) increase the proportion of quadrat with >1 mature abalone to >20%.
3. No direct mortality should be allowed at this time.
4. Illegal harvest/poaching on abalone by humans should continue to be actively discouraged through enforcement and public education.
5. Additional research in the field and computer ecological simulations are required to further understand abalone population dynamics as well as sea otter and abalone interactions on small and large spatial and temporal scales.
6. Consultations could be considered to enhance First Nation stewardship through agreements under which small enhancement projects are carried out at specific sites by local First Nation communities followed by a small harvest of abalone with strict controls when agreed upon conditions are achieved (e.g., abalone density reaches a certain threshold). The harvest would only take place if enhancement activities have been carried out.
7. Research and rebuilding projects should continue. If moving abalone or collecting broodstock, a SARA permit is necessary.
8. Impact assessment protocol outlined in Appendix 2 should be followed for proposed works and developments on, in or under the water.

References

Abalone Recovery Team. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in Canada. 22pp. http://www.-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/documents/AbaloneRecovStrategye.htm.

Adkins, B.E. 1996. Abalone surveys in south coast areas during 1982, 1985 and 1986. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 72-96.

Adkins, B.E., and Stefanson, A.P. 1979. North coast abalone survey in harvested areas, November 1978. Fish. Mar. Serv. Manuscr. Rep. 1500: 15 p.

Allee, W.C., A.E. Emerson, O. Park, T. Park, and K.P. Schmidt. 1949. Principles of Animal Ecology. Saunders, Philadelphia. 837 p.

Atkins, M., and Lessard, J. 2004. Survey of northern abalone, *Haliotis kamtschatkana*, populations along north-west Vancouver Island, British Columbia, May 2003. Can. Manuscr. Rep. Fish. Aquat. Sci. 2690: 12 p.

Atkins, M., Lessard, J., and Campbell, A. 2004. Resurvey of northern abalone, *Haliotis kamtschatkana*, populations in Southeast Queen Charlotte Islands, British Columbia, April 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2704: 37 p.

Babcock, R., and Keesing, J. 1999. Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. Can. J. Fish. Aquat. Sci. 56: 1668-1678

Black, K., Angel, D., and Eden, N. 2001. A review of the environmental impacts of marine cage aquaculture process of biofiltration relevant to impact mitigation, the biological process of marine invertebrates relevant to biofiltration, and biofouling on artificial surfaces. BIOFAQS Q5RS-2000-30305 Tech. Annex Annual Report Dec. 2001.

Boutillier, J.A., Carolsfeld, W., Breen, P.A., and Bates, K. 1984. Abalone survey in the Estevan Group and Aristazabal Island, May 1983. Can. Manuscr. Rep. Fish. Aquat. Sci. 1747: 60 p.

Boutillier, J.A., Carolsfeld, W., Breen, P.A., Farlinger, S., and Bates, K. 1985. Abalone resurvey in the southeast Queen Charlotte Islands, July 1984. Can. Manuscr. Rep. Fish. Aquat. Sci. 1818: 87 p.

Bower, S. 2000. Infectious diseases of abalone (*Haliotis* spp.) and risks associated with transplantation. Can. Spec. Public. Fish. Aquat. Sci. 130: 111-122.

Breen, P.A. 1980. Muscled mollusc: the northern abalone. Diver 6(6): 26-28.

Breen, P.A. 1986. Management of the British Columbia fishery for northern abalone (*Haliotis kamtschatkana*). Can. Spec. Public. Fish. Aquat. Sci. 92: 300-312.

Breen, P.A., and Adkins, B.E. 1979. A survey of abalone populations on the east coast of the Queen Charlotte Islands, August 1978. Fish. Mar. Serv. Manuscr. Rep. 1490: 125 p.

Breen, P.A., and Adkins, B.E. 1980a. Observations of abalone populations in Emily Carr Inlet and Lotbinière Bay, April 1980. Can. Manuscr. Rep. Fish. Aquat. Sci. 1576: 17 p.

Breen, P.A., and Adkins, B.E. 1980b. Spawning in a British Columbia population of northern abalone, *Haliotis kamtschatkana*. Veliger 23: 177-179.

Breen, P.A., and Adkins, B.E. 1981. Abalone surveys and tagging conducted during 1979. Can. Manuscr. Rep. Fish. Aquat. Sci. 1623: 88 p.

Breen, P.A., Adkins, B.E., and Heritage, G.D. 1978a. Observations of abalone and subtidal communities made during a survey of Queen Charlotte Strait and upper Johnstone Strait areas. Fish. Mar. Serv. Manuscr. Rep. 789: 91 p.

Breen, P.A., Adkins, B.E., and Sprout, P.E. 1982. Abalone populations on the west coast of Banks Island, June 1980. Can. Manuscr. Rep. Fish. Aquat. Sci. 1640: 42 p.

Breen, P.A., Stefanson, A.P., and Adkins, B.E. 1978b. North coast abalone surveys in harvested areas, spring 1978. Fish. Mar. Serv. Manuscr. Rep. 1480: 61 p.

Brown, L.D. 1991. Genetic variation and population structure in the blacklip abalone, *Haliotis rubra*. Aust. J. mar. Freshwat. Res. 42: 47-90.

Brown, L.D., and Murray, N.D. 1992. Population genetics, gene flow, and stock structure in *Haliotis rubra* and *Haliotis laevigata*. pp. 24-33 *in* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds). Abalone of the World - Biology, Fisheries and Culture. Fishing News Books, Oxford.

Burton, R.S., and Tegner, M.J. 2000. Enhancement of red abalone Haliotis rufescens stocks at San Miguel Island: reassessing a success story. Mar. Ecol. Prog. Ser. 202: 303-308.

Campbell, A. 1997. Possible criteria for reopening the northern abalone (*Haliotis kamtschatkana*) fishery in British Columbia. DFO Can. Stock Assess. Sec. Res. Doc. 1997/64: 47 p.

Campbell, A. 2000. Review of northern abalone, *Haliotis kamtschatkana*, stock status in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130. pp. 41-50.

Campbell, A., Brouwer, D., Rogers, J., and Miller, D.C. 2000a. Abalone resurvey in South East Queen Charlotte Islands, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2528: 29 p.

Campbell, A., and Cripps, K. 1998. Survey of abalone populations at Stryker Island, Tribal Group and Simonds Group, Central Coast of British Columbia, May 1997. Can. Manuscr. Rep. Fish. Aquat. Sci. 2451: 21 p.

Campbell, A., Lessard, J., and Jamieson, G.S. 2003. Fecundity and seasonal reproduction of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, Canada. J. Shellfish Res. 22: 811-818.

Campbell, A., Lucas, B., and Parker, G. 2000b. Discussion on an experimental approach for northern abalone stock rebuilding in British Columbia. DFO Can. Stock Assess. Sec. Res. Doc. 2000/047: 24 p.

Campbell, A., Manley, I., and Carolsfeld, W. 1992. Size at maturity and fecundity of the abalone, *Haliotis kamtschatkana* (Jonas), in northern British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2169: 47-65.

Campbell, A., Winther, I., Adkins, B., Brouwer, D., and Miller, D. 1998. Survey of the northern abalone (*Haliotis kamtschatkana*) in the central coast of British Columbia, May 1997. DFO Can. Stock Assess. Sec. Res. Doc. 1998/89: 28 p.

Carolsfeld, W., Farlinger, S., Kingzett, B.C., Sloan, N.A., and Thomas, G. 1988. Abalone resurvey in the southeast Queen Charlotte Islands, June 1987. Can. Manuscr. Rep. Fish. Aquat. Sci. 1966: 90 p.

Carter, S.K., VanBlaricom, G.R., and Allen, B.L. 2007. Testing the generality of the trophic cascade paradigm for sea otters: a case study with kelp forests in northern Washington, USA. Hydrobiologia 579: 233-249.

Castilla, J.C., Manríquez, P., Alvarado, J., Rosson, A., Pino, C., Espoz, C., Soto, R., Oliva, D., and Defeo, O. 1998. Artisanal “Caletas” as units of production and co-managers of benthic invertebrates in Chile. Can. Spec. Publ. Fish. Aquat. Sci. 125: 407-413.

Chamberlain, J., Fernandes, T.F., Read, P., Nickell, T.D., and Davies, I.M. 2001. Impacts of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments. ICES J. Mar. Sci. 58: 411–416.

Cooper, J., Wieland, M., and Hines, A. 1977. Subtidal abalone populations in an area inhabited by sea otters. The Veliger 20: 163-167.

Cripps, K., and Campbell, A. 1998. Survey of abalone populations at Dalain Point and Higgings Pass, Central Coast of British Columbia, 1995-96. Can. Manuscr. Rep. Fish. Aquat. Sci. 2445: 31 p.

Davies, K., Atkins, M., and Lessard, J. 2006. Survey of northern abalone, *Haliotis kamtschatkana*, populations in Queen Charlotte and Johnstone Straits, British Columbia, May 2004. Can. Manuscr. Rep. Fish. Aquat. Sci. 2743: 17 p.

Deacon, R.T. 1989. An empirical model of fishery dynamics. J. Env. Econ. Manag. 16: 167-183.

DFO. 2004a. Northern Abalone. DFO Science Stock Status Report.

DFO. 2004b. Practitioners guide to the Species at Risk Act (SARA) for habitat management staff.

DFO. 2004c. Proceedings of the National Peer Review Meeting on the Level of Allowable Harm for Newfoundland and Labrador Atlantic Cod, Laurentian North Atlantic Cod, Cusk and Bocaccio in Support of Species at Risk. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/040: 65 p.

DFO. 2005. DFO Marine Fish Habitat Information Requirements (HIR) for Finfish Aquaculture Projects.

Dowling, M.A., Hall, S.J., and McGarvey, R. 2004. Assessing population sustainability and response to fishing in terms of aggregation structure for greenlip abalone (*Haliotis laevigata*) fishery management. Can. J. Fish. Aquat. Sci. 61: 247-259

Edgar, G.J., Barrett, N.S., Morton, A.J., and Samson, C.R. 2004. Effects of algal canopy clearance on plant, fish and macroinvertebrate communities on eastern Tasmanian reefs. J. Exp. Mar. Biol. Ecol. 312: 67-87.

Farlinger, S., and Bates, K.T. 1986. Abalone survey in the Estevan Group and Aristazabal Island, June 1985. Can. Manuscr. Rep. Fish. Aquat. Sci. 1896: 45 p.

Farlinger, S., Thomas, G.A., Winther, I., and Carolsfeld, W. 1991. Abalone resurvey in the Estevan Group and Aristazabal Island, June 1989. Can. Manuscr. Rep. Fish. Aquat. Sci. 2104: 39 p.

Hanson, J., Helvey, M., and Strach, R. 2003. Non-fishing impacts to essential fish habitat and recommended conservation methods. Nat. Marine Fish. Service (NOAA Fisheries) Version 1. Southwest Region, Long Beach CA.

Harbo, R. 1997. Abalone Dive Fishery (closed). Can. MS Rep. Fish. Aquat. Sci. 2369: 86-92.

Haya, K., Burridge, L.E., and Chang, B.D. 2001. Environmental impact of chemical wastes produced by the salmon aquaculture industry. ICES J. Mar. Sci. 58: 492-496.

Hines, A.H. and Pearse, J.S. 1982. Abalones, shells, and sea otters: dynamics of prey populations in central California. Ecology 63: 1547-1560.

Hunt, J.W., and Anderson, B.S. 1989. Sublethal effects of zinc and municipal effluents on larvae of the red abalone *Haliotis rufescens*. Mar. Biol. 101: 545-552.

Ino, T. 1968. The abalone science and its propagation in Japan. Fish. Res. Bd Transl. Ser. 1078: 209 p.

Jackson, R.G. 1986. Effects of bark accumulation on benthic infaunal at a log transfer facility in Southeast Alaska. Mar. Pol. Bull. 17(6): 258-262.

Jamieson, G.S. 2001. Review of status of northern abalone, *Haliotis kamtschatkana*, in Canada. Canadian Field-Naturalist 115: 555-563.

Jones, R., DeFreitas, B., Sloan, N., Lee, L., von Boetticher, K., and Martin, G. 2003. Abalone stewardship in Haida Gwaii: forging a long term commitment. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 5-19.

Jubinville, B. 2000. Enforcing the fishery closure for northern (pinto) abalone (*Haliotis kamtschatkana*) in British Columbia (abstract). Can. Spec. Public. Fish. Aquat. Sci. 130: 52.

Kirkpatrick, B., Shirley, T.C. and O'Clair, C.E. 1998. Deep-water bark accumulation and benthos richness at log transfer and storage facilities. Alaska Fishery Res. Bull. 5:103–115.

Lessard, J., Atkins, M. and Campbell, A. 2007. Resurvey of northern abalone, *Haliotis kamtschatkana*, populations along the central coast of British Columbia, April 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2791: 35 p.

Lessard, J., Campbell, A., and Hajas, W. 2002. Survey protocol for the removal of allowable numbers of northern abalone, *Haliotis kamtschatkana*, for use as broodstock in aquaculture in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/126: 40 p.

Levitan, D.R., and Sewell, M.A. 1998. Fertilization success in free-spawning marine invertebrates: review of the evidence and fisheries implications. Can. Spec. Public. Fish. Aquat. Sci. 125: 159-164

Levitan, D.R., Sewell, M.A., and Chia, F.-S. 1992. How distribution and abundance influence fertilization success in the sea urchin *Strongylocentrotus franciscanus*. Ecology 73: 248-254

Lowry, L.F., and Pearse, J.S. 1973. Abalones and sea urchins in an area inhabited by sea otters. Mar. Biol. 23: 213-219

Lucas, B.G., Campbell, A., and Cripps, K. 1999. Resurvey of abalone populations at Tribal Group, Simonds Group and Stryker Island, Central Coast of British Columbia, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2487: 18 p.

McShane, P.E. 1992. Early life history of abalone: a review. pp. 120-138 *In* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds), Abalone of the World - Biology, Fisheries and Culture. Fishing News Books, Oxford.

McShane, P.E. 1995a. Estimating the abundance of abalone: the importance of patch size. Marine and Freshwater Research 46: 657-662

McShane, P.E. 1995b. Recruitment variation in abalone: its importance to fisheries management. Aust. J. mar. Freshwat. Res. 46: 555-570

McShane, P.E., Black, K.P., and Smith, M.G. 1988. Recruitment processes in *Haliotis rubra* (Mollusca: Gastropoda) and regional hydrodynamics in southeast Australia imply localised dispersal of larvae. J. Exp. Mar. Biol. Ecol. 124: 175-203.

Ministry of Agriculture and Lands. 2006. (http://www.agf.gov.bc.ca/fisheries/commercial/commercial_mp.htm; accessed Nov. 06, 2006)

Nichol, L.M., Watson, J.C., Ellis, G.M., and Ford, J.K.B. 2005. An assessment of abundance and growth of the sea otter population (*Enhydra lutris*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/094: 22 p.

Nordvarg, L. 2001. Predictive models and eutrophication effects of fish farms. Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 602. 44 pp. Uppsala, Sweden.

Otsfeld. 1982. Foraging strategies and prey switching in the California sea otter. Oecologia 53: 170-178.

Pearce, C.M., Ågerup, P., Alabi, A., Renfrew, D., Rosser, J., Whyte, G., and Yuan, F. 2003. Recent progress in hatchery production of pinto abalone, *Haliotis kamtschatkana*, in British Columbia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 29-44.

Pollard, S. 1992. Red abalone, *Haliotis rufescens*, relative impacts of recreational fisheries and sea otter predation on the abundance, size frequency, and microhabitat distribution of red abalone populations in central and northern California. M.Sc. Thesis, University of Santa Cruz, California.

Prince, J.D., Sellers, T.L., Ford, W.B., and Talbot, S.R. 1987. Experimental evidence for limited dispersal of haliotid larvae (genus *Haliotis*; Molluscs: Gastropoda). J. Exp. Mar. Biol. Ecol. 106: 243-263.

Prince, J., Walters, C., Ruiz-Avila, R., and Sluczanowski, P. 1998. Territorial user's rights and the Australian abalone (*Haliotis* sp.) fishery. Can. Spec. Publ. Fish. Aquat. Sci. 125: 367-375.

Quayle, D.B. 1971. Growth, morphometry and breeding in the British Columbia abalone (*Haliotis kamtschatkana* Jonas). Fish. Res. Bd Can. Tech. Rep. Ser. 279: 84 p.

Ralls, K., and Ballou, J.D. 1992. Managing genetic diversity in captive breeding and reintroduction programs. Trans. 57th N. Am. Wildl. Nat. Res. Conf. : 263-282.
Roberts, R.D., Kawamura, T., and Takami, H. 1999. Abalone recruitment - an overview of some recent research in New Zealand, Australia and Japan. Bull. Tohoku Natl. Fish. Res. Inst. 62: 95-107.
Sea Otter Recovery Team. 2003. National Recovery Strategy for the Sea Otter (*Enhydra lutris*) in Canada. Fisheries and Oceans Canada. 60 pp.
Shepherd, S.A., and Baker, J.L. 1998. Biological reference points in an abalone (*Haliotis laevigata*) fishery. Can. Spec. Public. Fish. Aquat. Sci. 125: 235-245
Shepherd, S.A., and Breen, P.A. 1992. Mortality in abalone: its estimation, variability and causes. *in* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds). Abalone of the World - Biology, Fisheries and Culture. Fishing News Books, Oxford.
Shepherd, S.A., and Brown, L.D. 1993. What is an abalone stock: implications for the role of refugia in conservation. Can. J. Fish. Aquat. Sci. 50: 2001-2009
Shepherd, S.A., and Partington, D. 1995. Studies on southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. Marine and Freshwater Research 46: 669-680.
Shepherd, S.A., Woodby, D., Rumble, J.M., and Avalos-Borja, M. 2000. Microstructure, chronology and growth of the pinto abalone, *Haliotis kamtschatkana*, in Alaska. J. Shellfish Res. 19, 219-228.
Simenstad, C.A., Estes, J.A., and Kenyon, K.W. 1978. Aleuts, sea otters, and alternate stable-state communities. Science 200: 403-411
Simizu, T. and Uchino, K. 2004. Effects of extensive seeding on abalone *Haliotis discus discus* abundance on the Pacific coast of boso peninsula, Japan. J. Shellfish Res. 23: 1209-1211.
Sinclair, A.R.E., and Byrom, A.E. 2006. Understanding ecosystem dynamics for conservation of biota. J. Animal Ecol. 75: 64-79.
Sloan, N.A., and Breen, P.A. 1988. Northern abalone, *Haliotis kamtschatkana* in British Columbia: fisheries and synopsis of life history information. Can. Spec. Public. Fish. Aquat. Sci. 103: 46 pp
Soulé, M.E., Estes, J.A., Berger, J., and Martinez del Rio, C. 2003. Ecological effectiveness: Conservation goals for interactive species. Conserv. Biol. 17: 1238-1250.
Tegner, M.J. 1993. Southern California abalones: can stocks be rebuilt using marine harvest refugia? Can. J. Fish. Aquat. Sci. 50: 2010-2018
Tegner, M.J. 2000. Abalone (*Haliotis* spp.) enhancement in California: what we've learned and where we go from here. Can. Spec. Public. Fish. Aquat. Sci. 130: 61-71.
Tegner, M.J., and Butler, R.A. 1985. Drift-tube study of the dispersal potential of green abalone (*Haliotis fulgens*) larvae in the southern California Bight: implications for the recovery of depleted populations. Mar. Ecol. Prog. Ser. 26: 73-84.
Tegner, M.J., Haaker, P.L., Riser, K.L., and Vilchis, L.I. 2001. Climate variability, kelp forests, and the southern California red abalone fishery. J. Shellfish Res. 20: 755-763.
Templeton, A.R. 1990. The role of genetics in captive breeding and reintroduction programs for species conservation. Endangered Species Update 8: 15-17.
Thomas, G., and Campbell, A. 1996. Abalone resurvey in Aristazabal Island, the Estevan Group and Banks Island, June 1993. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 97-109.
Thomas, G., Farlinger, S., and Carolsfeld, W. 1990. Abalone resurvey in the southeast Queen Charlotte Islands in 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2099: 66-82.

Troell, M., Robertson-Andersson, D., Anderson, R.J., Bolton, J.J., Maneveldt, G., Halling, C., and Probyn, T. 2006. Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. Aquaculture 257: 266-281.

Wallace, S.S. 1999. Evaluating the effects of three forms of marine reserve on northern abalone populations in British Columbia, Canada. Conserv. Biol. 13: 882-887.

Watson, J. 1993. The effects of sea otter (*Enhydra lutris*) foraging on shallow rocky communities off northwestern Vancouver Island, British Columbia. Ph.D., University of California, Santa Cruz. 169 p.

Watson, J. 2000. The effects of sea otters (*Enhydra lutris*) on abalone (*Haliotis* spp.) populations. Can. Spec. Public. Fish. Aquat. Sci. 130: 123-132.

Watson, J.C., Ellis, G.M., Smith, T.G., and Ford, J.K.B. 1997. Updated status of the sea otter, *Enhydra lutris*, in Canada. Canadian Field-Naturalist 111: 277-286.

Wendell, F. 1994. Relationship between sea otter range expansion and red abalone abundance and size distribution in central California. Calif. Fish Game 80: 45-56.

Wild, P.W. and Ames, J.A. 1974. A report on the sea otter, *Enhydra lutris* L., in California. Calif. Fish Game Mar. Res. Tech. Rep. 20.

Winsby, M., Sander, B., Archibald, D., Daykin, M., Nix, P., Taylor, F.J.R., and Munday, D. 1996. The environmental effects of salmon netcage culture in British Columbia - A literature review. Report prepared for the Ministry of Environment Lands and Parks, Victoria, BC, by Hatfield Consultants Ltd and EVS Environmental Consultants.

Winther, I., Campbell, A., Thomas, G.A., Adkins, B.E., and Clapp, B.G. 1995. Abalone resurvey in the southeast Queen Charlotte Islands in 1994. Can. Manuscr. Rep. Fish. Aquat. Sci. 2273: 43 p.

Withler, R.E., A. Campbell, S. Li, K.M. Miller, D. Brouwer, and B.G. Lucas. 2001. High levels of genetic variation in northern abalone *Haliotis kamtschatkana* of British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/097: 27 p.

Withler, R.E., Campbell, A., Li, S., Miller, K.M., Brouwer, D., Supernault, K.J., and K.M. Miller. 2003. Implications of high levels of genetic diversity and weak population structure for the rebuilding of northern abalone in British Columbia, Canada. J. Shellfish Res. 22: 839-847.

Table 1. Human-influenced relative mortality (direct and indirect) to abalone populations, in order of importance. Relative mortality scale: High = F $\geq$0.10; Medium = 0.10>F>0.03; Low = F < 0.03; Minimal = F < 0.01

Human-influenced activity	**Relative Mortality**	**Comment**
Illegal harvest	High	
Sea otter predation	High	
Possible directed fishing	Medium - localized	Prior rebuilding work necessary and harvest allowed only above set target
Habitat alterations - Finfish aquaculture	Low	Assumes 'Impact Assessment Protocol' (Appendix 2) is followed
Habitat alterations - Log booms and log dumps	Low	Follow 'Impact Assessment Protocol' (Appendix 2)
Habitat alterations – Dredging	Low	Follow 'Impact Assessment Protocol' (Appendix 2)
Abalone aquaculture	Low	Combined with rebuilding work: beneficial
Fisheries on food supplies (i.e. kelp harvest)	Low – localized	
Scientific research	Minimal	Incidental mortality only (e.g., tagging), no direct mortality allowed
Rebuilding efforts - Larvae and juvenile outplanting	Minimal	All outplanting approved by I&T Committee: beneficial
Rebuilding efforts - Adult aggregation	Minimal	Requires a SARA permit: beneficial

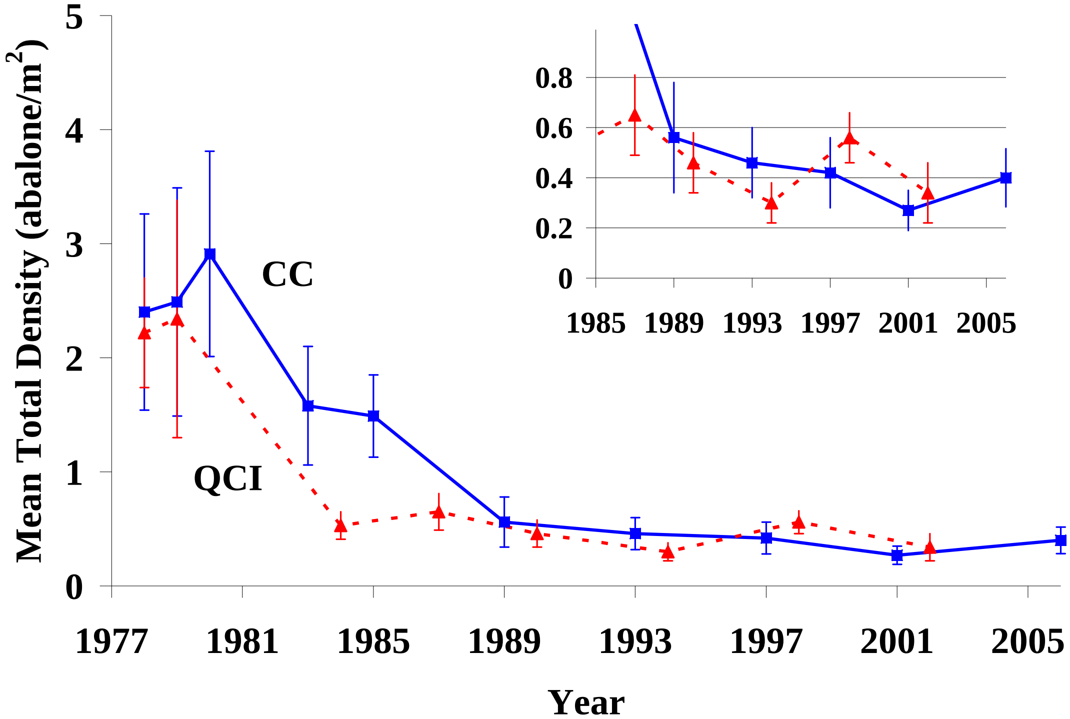


Figure 1. Mean density of exposed abalone, all sizes, from all surveys in the Central Coast (CC) (solid line) and the Queen Charlotte Islands (QCI) (dashed line). Error bars represent two standard errors. Inset graph displays greater resolution of densities for survey years after 1985.

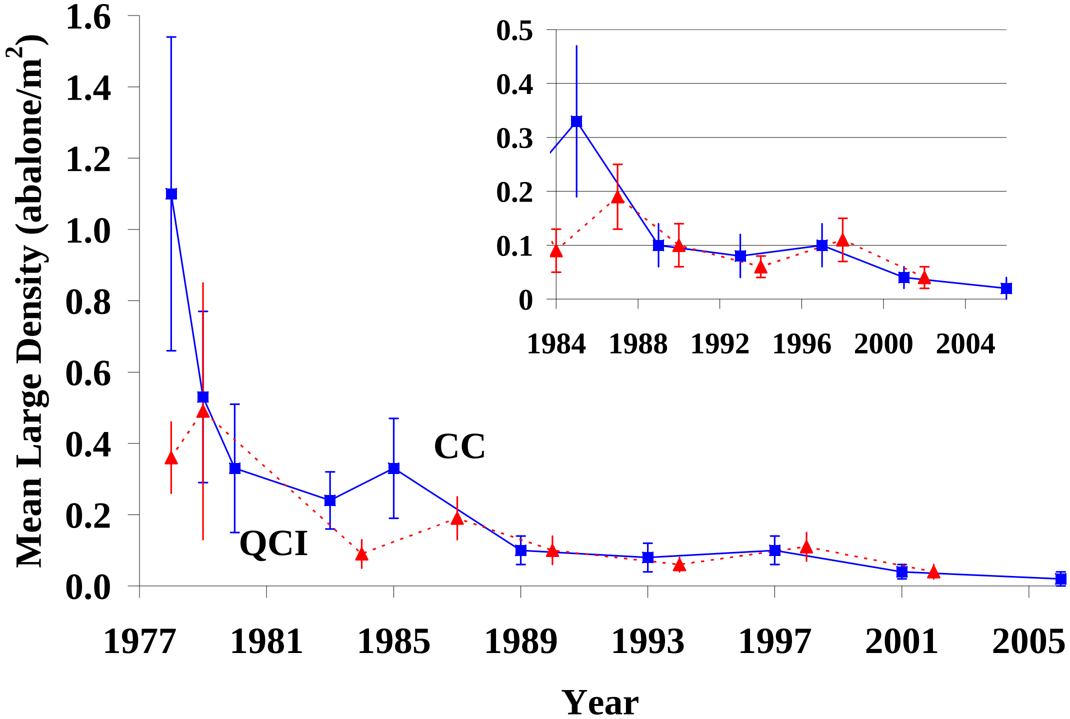


Figure 2. Mean density of large (≥100mm SL) abalone from all surveys in the Central Coast (CC) (solid line) and the Queen Charlotte Islands (QCI) (dashed line). Error bars represent two standard errors. Inset graph displays greater resolution of densities for survey years after 1985.

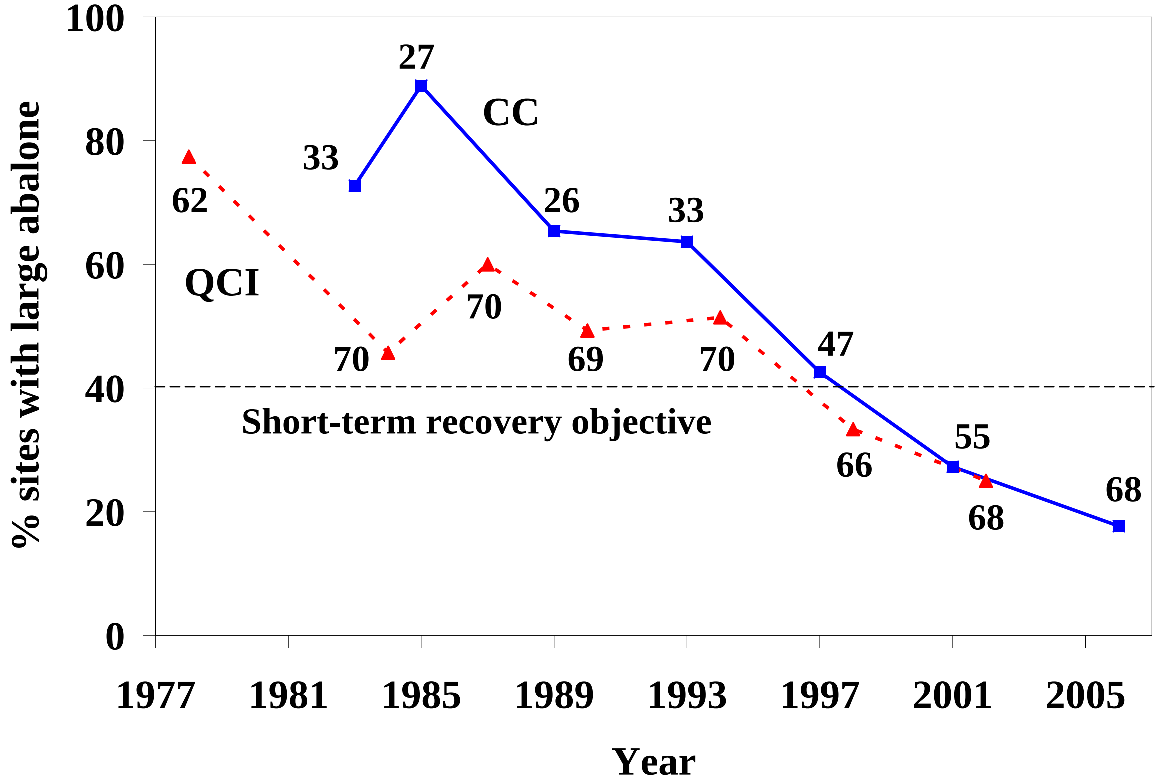
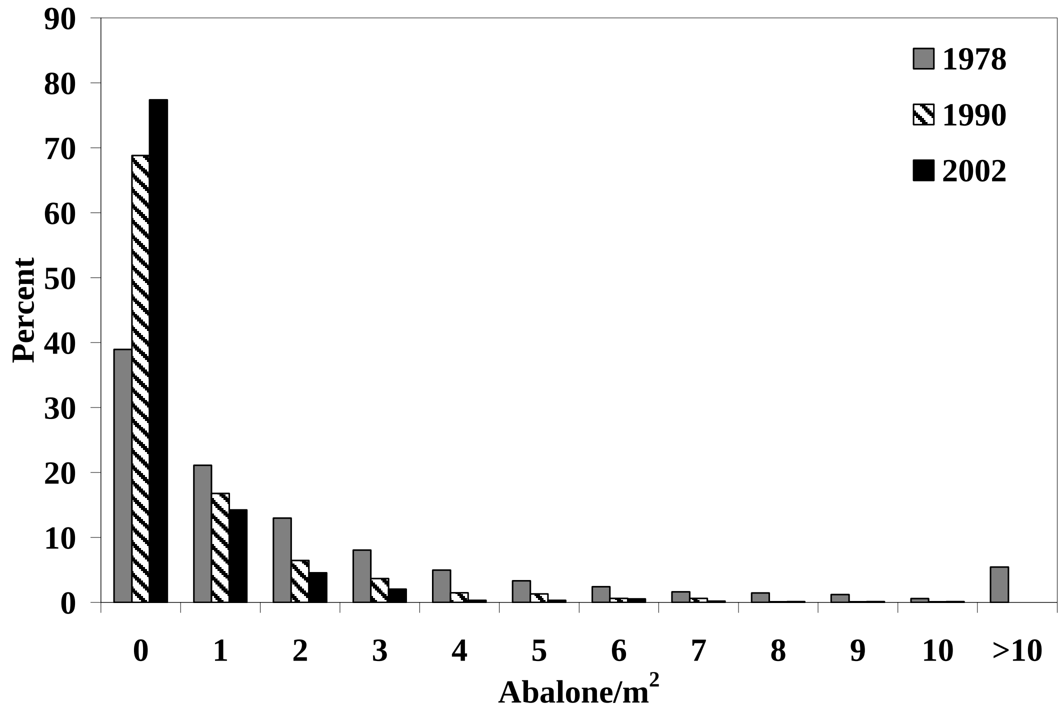


Figure 3. Percent of repeated index sites **with** large abalone (≥100 mm SL) from surveys in the Central Coast (CC) (solid line) and the Queen Charlotte Islands (QCI) (dashed line) (some years were excluded due to small number of 'index sites' in those years). Numbers are sample sizes.



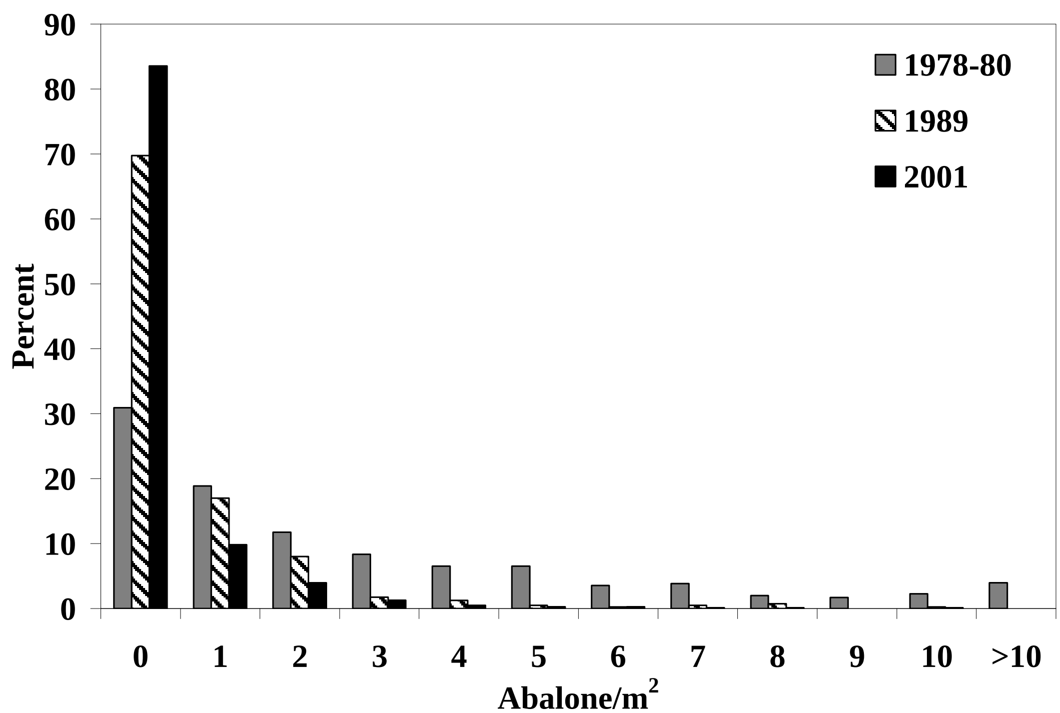


Figure 4. Percentage of surveyed quadrats with different abalone counts (all sizes) from all sites. Top graph: Queen Charlotte Islands during 1978, 1990 (last survey year when fisheries were opened) and 2002 surveys; Bottom graph: Central Coast during 1978-80 (combined surveys), 1989 (last survey year when fisheries were opened), and 2001 surveys.

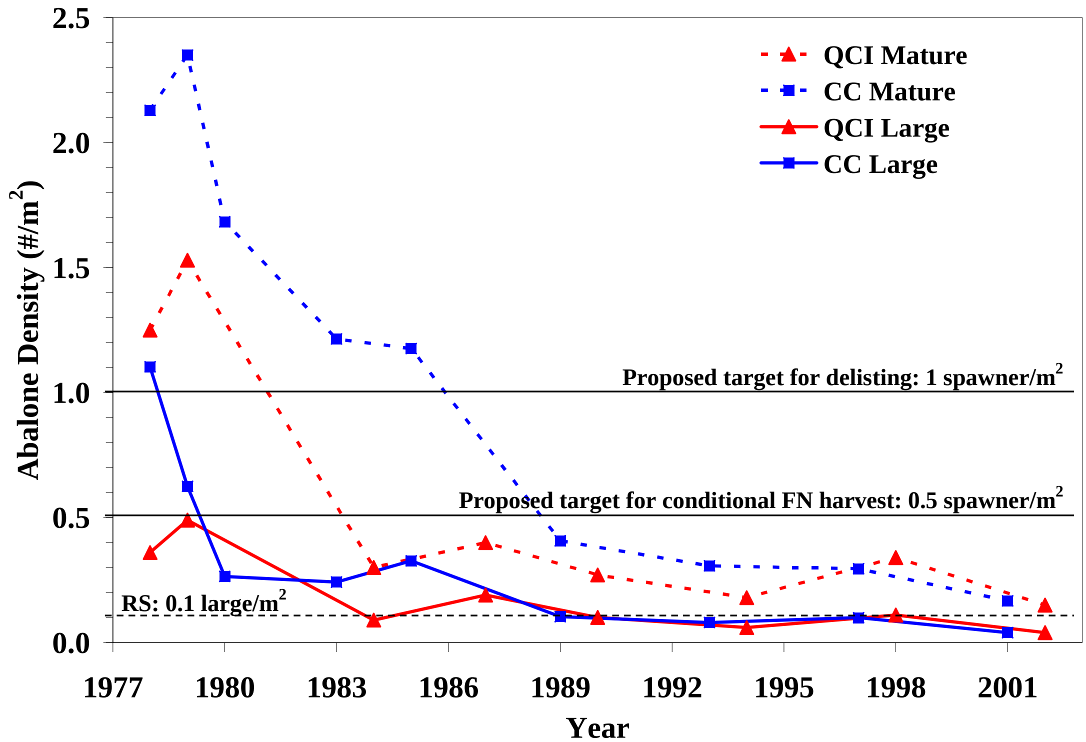


Figure 5. Mature (≥70mm SL) (dashed lines) and large (≥100mm SL) (solid lines) abalone densities from index sites surveys in QCI (triangles) and CC (squares). The lines across indicate the proposed recovery targets (solid lines) and the existing short-term recovery objective from the abalone recovery strategy (dashed line) (Abalone Recovery Team 2002).

Appendix 1 Abalone population model

Abalone population model

by

Zane Zhang

1. Introduction.

All fisheries on northern abalone (*Haliotis kamtschatkana*) stocks were closed in 1990 in British Columbia due to greatly reduced abundances of abalone populations. Sizes of abalone populations have remained low or even decreased since the closure. The objectives of this paper are to analyze time series survey data on northern abalone populations in British Columbia using computer simulation models to estimate mortality and stock recruitment relationships as well as predict population trends under different mortality values. The results will provide guidance for the recovery targets of abalone populations.

2. Material and Methods.

2.1. Geographic Locations

This modelling study was conducted for abalone populations in two geographic areas: Queen Charlotte Island (QCI) and Central Coast (CC) of British Columbia. QCI is divided into seven sub areas (Atkins et al. 2004), and CC is divided into nine sub areas (Lessard et al. 2007) (Table 1). The model is derived from surveys conducted during 1978-2002, usually with intervals of 4 years between consecutive surveys (Table 1).

2.2. Size-specific Proportion of Cryptic Abalone

Juvenile northern abalone (10-70 mm shell length (L)) are typically cryptic and are often found under rocks or in crevices, whereas the majority of adults (>70 mm L) are found on exposed rock surfaces (Sloan and Breen 1988, Cripps and Campbell 1998). To model abalone population dynamics, we need to know the proportions of cryptic abalone at different shell lengths. In the 1984 (Boutillier et al. 1985), 1987 (Carolsfeld et al. 1988) and 1990 (Thomas et al. 1990) surveys in QCI, extra efforts were made to search for and record (other surveys had searched for but had not recorded) cryptic abalone. We used the survey data from these three surveys to study the relationship between the proportion of cryptic abalone and shell length. We used a generalized linear model to describe the relationship, assuming a binomial distribution error structure with the logit link function (McCullagh and Nelder 1989). Abalone shell lengths (*L*) in mm were log-transformed before fitting the model:

$$y = \alpha + \beta \log(L) + \varepsilon \qquad (1)$$

where α and β are the model parameters, ε is the error variability from a binomial distribution, and $y = \log\left(\frac{P_L}{1-P_L}\right)$ where P_L is the probability of being cryptic at shell length L.

The parameters α and β were estimated to be 13.85 (se = 2.18) and -3.69 (se = 0.53) respectively. The probability of being cryptic at shell length L can, therefore, be estimated as:

$$P_L = \frac{\exp\left(13.85 - 3.69\log(L)\right)}{1 + \exp\left(13.85 - 3.69\log(L)\right)} \quad (2)$$

2.3. Abalone Growth Model

A number of von Bertalanffy growth equations were established for the abalone populations in QCI (Breen 1986). We chose to use the mean values for the parameters k (= 0.265) and L_∞ (112.6) in this study. The growth model was used to determine the size of age 3 and 4 juvenile as well as the size of adult abalone in a previous or subsequent survey to estimate mortality. As the sample size from each individual sub area is too small for the analyses, we pooled together the data from the surveys conducted in QCI or CC in years shown in bold in Table 1.

2.4. Abalone Density Estimation

We estimated mean abalone density and standard error through bootstrapping for each of the 7 sub areas in QCI and each of the 9 sub areas in CC. One thousand bootstraps were conducted. In each bootstrapping, the survey sites were randomly selected with replacement, and quadrats in each of the chosen sites were then randomly selected with replacement. Abalone density was estimated simply by dividing the total number of abalone in the selected quadrats by the total number of selected quadrats. The mean density and standard error were calculated from the 1000 estimated densities. Density of abalone for any particular size group was calculated as the product of the density of all sized abalone and the proportion of abalone in this size group in the sample.

2.5. Estimation of Mortality Rate

Using the survey data and the growth model, we estimated the mortality rates, Z, in two ways. In the first method, forward-calculation (section 2.5.1), we used the density estimate of cryptic and exposed abalone of all sizes in one survey to calculate the density of cryptic and exposed abalone larger than a selected size (70 or 80 mm L) at the time the subsequent survey was conducted. In the second method, back-calculation (section 2.5.2), we used the density estimate of cryptic and exposed abalone larger than a selected size range (50-70 mm L or 60-80 mm L) in one survey to back-calculate the density of cryptic and exposed abalone in the selected size range at the time the previous survey was conducted. We estimated Z by comparing the calculated density with the survey-derived density. Surveys conducted before 1990 were not used, because the fishery was not closed until 1990.

2.5.1. Forward-calculation Method

Abalone length at the subsequent survey time was estimated by rearranging the von-Bertalanffy equation:

$$L_2 = L_\infty - \exp(-k \times t)(L_\infty - L_1) \quad (3)$$

where t is the number of years between this survey and subsequent one, and the subscripts 1 and 2 indicate this survey and subsequent survey respectively.

Density of both cryptic and exposed abalone >70 or 80mm L was estimated as:

$$\hat{N}_2 = D_1 \times \exp(-Z \times t) \frac{\sum_L N_{1L} / (1 - P_L)}{TN_1} \quad (4)$$

where D is the estimated density of all sized exposed abalone in this survey except for year 1990 for QCI, Z is the mortality rate to be estimated (see below), N_L is the number of abalone at shell length L, which is expected to be >70 or >80 mm L at the subsequent survey time, P_L is the probability of being cryptic at shell length L, TN is the total number of measured abalone in this survey, and t is the number of years between this survey and subsequent one. For the 1990 survey in QCI, both cryptic and exposed abalone were observed, $\hat{N}$ was estimated without using the term $(1 - P_L)$. The survey-derived density of both cryptic and exposed abalone was estimated to be:

$$N_2 = D_2 \times \frac{\sum_L N_{2L} / (1 - P_L)}{TN_2} \quad (5)$$

where D is the estimated density of all sized exposed abalone in the subsequent survey, and N_L is the number of measured abalone at shell length L larger than the preset size at the subsequent survey.

A large proportion of abalone which are larger than 70 or 80 mm L result from the growth of smaller abalone observable in the previous survey. A small proportion results from recruitment, i.e. abalone that settled in the previous survey year and have grown to >70 or >80 mm L. The number of recruits among the abalone >70 or >80mm L was estimated to be:

$$N_R = R \times P \quad (6)$$

where R is the number of recruits randomly generated using the stock-recruitment model described in section 2.6, P is the proportion of recruits >70 or >80mm L. The value for P was calculated by assuming that shell lengths of the recruits are normally distributed with the mean estimated from the growth model and a coefficient of variation of 0.08.

Various Z values were trialed, and Z was estimated by minimizing the summed squared difference between $N - N_R$ and $\hat{N}$. To assess the variation in the Z estimation, 999 Monte Carlo simulations were conducted. In each simulation, survey-derived densities were randomly regenerated using the estimated mean density and standard error.

2.5.2. Back-calculation Method.

To back-calculate shell length, the von-Bertalanffy equation was re-arranged:

$$L_1 = L_\infty - \exp(k \times t)(L_\infty - L_2) \qquad (7)$$

where t is the number of years between this survey and previous one, and L is the shell length. The subscripts 1 and 2 indicate the previous survey and this survey respectively. The size range was selected to be either 50-70 mm L or 60-80 mm L. Density of both cryptic and exposed abalone within the selected size range at the previous survey time was estimated as:

$$\hat{N}_1 = D_2 \times \exp(Z \times t) \frac{\sum_L N_{2L} / (1 - P_L)}{TN_2} \qquad (8)$$

where D is the estimated density of all sized exposed abalone in this survey, Z is the mortality rate to be estimated (see below), N_L is the number of measured abalone at shell length L at this survey, which is estimated to have been within the selected size range at the previous survey, P_L is the probability of being cryptic at shell length L, TN is the total number of measured abalone in this survey, and t is the number of years between the previous and this survey. The survey-derived density of both cryptic and exposed abalone was estimated to be:

$$N_1 = D_1 \times \frac{\sum_L N_{1L} / (1 - P_L)}{TN_1} \qquad (9)$$

where N_L is the number of measured abalone at shell length L within the preset size range at the previous survey, and D is the estimated density of all sized exposed abalone at the previous survey except for year 1990 in QCI. For the 1990 survey in QCI, both cryptic and exposed abalone were observed, N was calculated without using the term $(1 - P_L)$.

Various Z values were trialed, and Z was estimated by minimizing the summed squared difference between N and $\hat{N}$. To assess the variation in the Z estimation, 999 Monte Carlo simulations were conducted in the same way as described above.

2.6. Stock and Recruitment

Abalone has a short planktonic larval stage which lasts for 5-11 days (Olsen 1984, Pearce et al. 2003), and dispersal of abalone larvae is likely to be limited (Sloan and Breen 1988). We, therefore, estimate the correlation between spawning stock biomass and recruitment for each of the seven sub areas in QCI and for each of the nine sub areas in CC. Size at 100% maturity for northern abalone is approximately 70 mm L (Campbell et al. 1992). Spawning stock biomass was estimated to be the biomass of abalone $\geq$ 70 mm L/ m^2. We used the equation $W = 0.0000578L^{3.2}$ to convert shell length (L in mm) into body weight (W in g). The two parameter values are the means estimated by Breen and Adkins (1982).

To correlate spawning stock biomass with the corresponding recruitment, we estimated the spawning biomass of both cryptic and exposed abalone at one survey and density of cryptic and exposed abalone at age 3 or 4 at the subsequent survey depending on the interval between the two consecutive surveys. For instance, to correlate the spawning biomass in the 1987 survey with the recruitment in the 1990 survey, we estimated density of age 3 abalone in 1990; to correlate the spawning biomass in the 1990 survey with the recruitment in the 1994 survey, we estimated density of age 4 abalone in 1994.

Abalone cannot be aged easily, therefore the proportion of abalone at the interested age was estimated using the growth model (section 2.3). We combined the survey data from all the surveys in the 7 sub areas of QCI or in the 9 sub areas of CC, because the measured sample size was small for each sub area. We assume that shell length (L) for each age is normally distributed and overlap of the length frequency distribution for one age group over the means for the two neighbouring age groups is negligibly small. For instance, nearly all age 4 abalone are larger than the mean L of age 3 abalone, but smaller than the mean L of age 5 abalone. We also assume that coefficient of variation (cov) is the same for the each L distribution. We set cov to be 0.08, so that the overlap is not too substantial.

We used the growth model to calculate the mean shell length, $\bar{L}_{a-1}$, $\bar{L}_a$ and $\bar{L}_{a+1}$, corresponding to ages $a-1$, a and $a+1$. Assuming the numbers of abalone for age $a-1$, a and $a+1$ to be N_{a-1}, N_a and N_{a+1} respectively, we calculated the expected number of abalone at each shell length between $\bar{L}_{a-1}$ and $\bar{L}_{a+1}$ as:

$$\hat{N}_L = \frac{N_{a-1}\hat{P}_{a-1,L}}{\sum_{L=\bar{L}_{a-1}}^{\bar{L}_{a+1}} \hat{P}_{a-1,L}} + \frac{N_a\hat{P}_{a,L}}{\sum_{L=\bar{L}_{a-1}}^{\bar{L}_{a+1}} \hat{P}_{a,L}} + \frac{N_{a+1}\hat{P}_{a+1,L}}{\sum_{L=\bar{L}_{a-1}}^{\bar{L}_{a+1}} \hat{P}_{a+1,L}}, \tag{10}$$

where $\hat{P}_{a-1,L}$, $\hat{P}_{a,L}$, and $\hat{P}_{a+1,L}$ are the expected proportions of abalone at shell length L among abalone at ages $a-1$, a and $a+1$ respectively. $\hat{P}_{a-1,L}$, $\hat{P}_{a,L}$, and $\hat{P}_{a+1,L}$ were calculated based on the assumed normal distributions. The expected proportion of abalone at shell length L ($\hat{P}_L$) was estimated by dividing $\hat{N}_L$ by N, the observed number of abalone between $\bar{L}_{a-1}$ and $\bar{L}_{a+1}$.

We assumed a multinomial distribution for the number of abalone at each shell length, and the log likelihood is:

$$Likelihood = \sum_{\bar{L}_{a-1}}^{\bar{L}_{a+1}} N_L \log(\hat{P}_L) \tag{11}$$

where N_L is the number of abalone at shell length L. Various combinations of values for N_{a-1}, N_a and N_{a+1} were trialed until the maximum likelihood was reached. Among the abalone at shell length L the proportion of age a was calculated to be:

$$\hat{Q}_{L,a} = \frac{\hat{N}_a \hat{P}_{a,L}}{\sum_{\alpha=a-1}^{a+1} \hat{N}_\alpha \hat{P}_{\alpha,L}} \qquad (12)$$

where $\hat{N}_a$ is the maximum likelihood estimate of N_a. We assume that the estimate of $\hat{P}_{a,L}$ is applicable to the sample for each sub area. Thus, the number of abalone at age a in each sample is:

$$R_a = \sum_{L=\bar{L}_{a-1}}^{\bar{L}_{a+1}} N_L \times \hat{Q}_{a,L} \qquad (13)$$

where N_L is the number of abalone at shell length L ($\bar{L}_{a-1} \le L \le \bar{L}_{a+1}$) in a sample.

For CC, only density of cryptic and exposed abalone at age 4 was estimated. For QCI, density of cryptic and exposed abalone at age 4 was estimated for years of 1994, 1998 and 2002, whereas density of cryptic and exposed abalone at age 3 was estimated for years of 1987 and 1990. For consistency, recruitment in this study is represented by the density of cryptic and exposed abalone at age 4. Densities of age 4 abalone in 1988 and 2001 were thus estimated from the densities of age 3 abalone in 1997 and 2000 in QCI using a mortality rate of 0.3. We fit a separate Beverton-Holt stock-recruitment model to the data for QCI and CC with a multiplicative error structure:

$$R = \frac{a \times S}{1 + b \times S} \exp(\varepsilon) \qquad (14)$$

where R is the recruitment represented by number of both cryptic and exposed age-4 abalone/m^2, S is the spawning biomass represented by matured biomass in kg/m^2, a and b are the model parameters, and ε is a random error variability from a normal distribution, $N(0, \sigma^2)$. The ratio of a and b determines the maximum recruitment. For CC, a and b were estimated to be 1.73 and 2.8 respectively, suggesting that the maximum recruitment would be 0.62/m^2 (Fig. 2). The coefficient of determination, R^2, was equal to 0.56, and σ was estimated to be 0.61. For QCI, a and b were estimated to be 22.86 and 409.47 respectively, suggesting that the maximum recruitment would only be 0.056/m^2 and mean recruitment does not practically change when the spawning biomass is above 0.02 kg/m^2 (Fig. 3). This stock-recruitment curve does not appear to be biologically sensible. The carrying capacity for the recruitment is likely to be much higher, and increases in biomass from the current low level are likely to result in higher recruitment. We, therefore, abandoned the mathematically fitted model, and re-fit the model in a biological manner. We assumed that the maximum recruitment in QCI is the same as the one estimated for CC. Thus, the ratio of a/b is fixed to be 0.62, and only one of the two parameters (either a or b) needs to be estimated. The parameters, a and b, were estimated to be 1.59 and 2.56 respectively, and the resultant stock and recruitment function appears to be much more meaningful, and was used for simulation studies (Fig. 3).

The Beverton-Holt stock-recruitment model implicitly assumes that the survival rate for young animals before the recruitment age is made up of both density-independent and density-dependent effects. Existing of the assumed density-dependent effect would result in a higher survival rate for young animals with decreasing density of spawning biomass. It is possible that the abalone population might not have the density-dependent effect at low density levels. We also fit a density-independent stock-recruitment model to the estimated spawning stock biomass and recruitment data:

$$R = \kappa \times S \exp(\varepsilon) \qquad (15)$$

where κ is the density-independent parameter. As this stock-recruitment relationship is not realistic for large population size, we only fit the model to the data with the estimated spawning biomass less than 0.2 kg/m^2. One data set was excluded for QCI, and two data sets were excluded for CC.

2.7. Comparison of Simulated and Survey-derived Abalone Densities

The stock and recruitment functions were established by correlating the estimated spawning biomass with density of recruits in each individual sub area. Simulations, however, were conducted for the entire geographic region. We tested the reliability of our model predictions by comparing the model simulation results with observed survey results. The commercial fishery ended in 1990 due to low abalone population levels. The tests were carried out during the years after the commercial fishery ended. The simulation started in 1990 and ended in 2002 for QCI, and started in 1993 and ended in 2006 for CC.

The simulation was conducted using the established Beverton-Holt stock-recruitment model, the growth model, and estimated mortality rates. Maximum age was assumed to be 20 years, and abalone reaching age 21 would be removed from the simulated population. The density estimates of exposed abalone and size frequencies of the 1990 survey (for QCI) and 1993 survey for (CC) were used to set up the initial population structure. The size interval for each age was set according to the growth model. For age a, the size interval was defined to be between the mid-point of $\bar{L}_{a-1}$ and $\bar{L}_a$ and the mid-point of $\bar{L}_a$ and $\bar{L}_{a+1}$. Abalone within this interval was assigned to be age a. Abalone larger than L_∞ was assigned to be age of 20 years.

Spawning biomass was estimated to be the matured biomass (in kg) of abalone $\geq$ 70 mm L/m^2, and recruitment (number of age 4 abalone/m^2) were randomly generated from the Beverton-Holt stock-recruitment model. One thousand simulations were conducted, and in each simulation variations in the stock-recruitment functions and the mortality rates were incorporated.

2.8. Trajectory of Population Growth

The abalone population dynamics were simulated for the next 50 years starting from the latest survey available (2002 for QCI and 2001 for CC). The simulations were conducted in the similar way as described above, using the same Beverton-Holt stock-recruitment models and growth model. The density estimates of exposed abalone and size frequencies of the 2002 survey (for QCI) and 2001 survey for (CC) were used to set up the initial population structure. Impact of various mortality rates on the population growth was examined.

3. Results

When abalone are <20 mm L, the cryptic proportion is very high (Fig. 1). As observed in surveys (Cripps and Campbell 1998), the cryptic proportion declines with increasing shell length (Fig. 1).

There are considerable variations in the stock-recruitment relationships, and variation in recruitment increase with increasing spawning biomass (Figs. 2, 3). The maximum mean recruitment in CC was estimated to be 0.62/m^2. When this recruitment carrying capacity was used for abalone populations in QCI, the resultant Beverton-Holt stock-recruitment model appears to be reasonable as compared with the one fitted in the mathematical manner (Fig. 3). The fitted density-independent stock-recruitment curves appear to be comparable to the fitted Beverton-Holt curves for both QCI and CC when spawning biomass is low (<0.1 kg/m^2) (Figs. 2, 3). Thus, only Beverton-Holt models were used in the simulations.

Estimated mortality rates using the backward method are lower than those using the forward method in Table 2. Comparison of observed and simulated exposed densities using the two different morality rates seem to indicate, at least for CC, that the rate estimated by the forward method is closer to reality.

With a mortality rate of 0.23 in the QCI simulation, the survey-derived mean densities of exposed abalone in 1998 and 2002 are within the 90% confidence bounds of simulated densities, and the observed mean density of exposed abalone in 1994 is outside the bound (Fig. 4). This simulation suggests that the abalone population is sustainable at the current low level, as the density trend does not appear to be increasing or decreasing considerably. With a mortality rate of 0.29 in the QCI simulation, the survey-derived mean densities of exposed abalone in 1994 and 2002 are within the 90% confidence bounds, and the survey-derived mean density of exposed abalone in 1998 is outside the bound (Fig. 5). This simulation suggests that the abalone population is generally still decreasing which is more likely to be closer to the reality, since large abalone densities have decreased in QCI (Atkins et al. 2004).

With a mortality rate of 0.21 in the CC simulation, the survey-derived mean densities of exposed abalone in 1997 and in 2006 are within the 90% confidence bounds, and the survey-derived mean density of exposed abalone in 2001 is outside the bound (Fig. 6). This simulation suggests that the abalone population is in general slightly increasing. With a mortality rate of 0.36 in the CC simulation, the observed mean densities of exposed abalone in 1997, 2001, and 2006 are all within the 90% confidence bounds (Fig. 7). This simulation, therefore, is more reasonable than the simulation with a mortality rate of 0.21, indicating that the abalone population is in general still decreasing.

With a mortality rate of 0.23, the 50-year simulation suggests that abalone population in QCI would sustain at the current level (Fig. 8). With a mortality rate of 0.29, the 50-year simulation suggests that abalone population in QCI would continue to decrease. The mean total density of exposed abalone would be below $0.1/m^2$ in 50 years (Fig. 9). With a mortality rate of 0.21, the 50-year simulation suggests that abalone population in CC would be increasing. The mean total density of exposed abalone would be around $0.6/m^2$ in 50 years (Fig. 10). With a mortality rate of 0.36, the 50-year simulation suggests that abalone population in CC would be decreasing. The mean total density of exposed abalone would be below $0.05/m^2$ in 50 years (Fig. 11).

Mortality rates will have a substantial impact on the growth of the abalone population. Results from simulations varying mortality rates suggest that the abalone populations in QCI and CC would increase with mortality rate below 0.2, would be sustainable with mortality rate between 0.2 and 0.25, and would decrease with mortality rate above 0.25 (Figs. 12, 13).

When mortality rates remain high, the exposed abalone population (all sizes) would decline to a density level ($0.001/m^2$) which probably would not be sustainable and lead to eventual extinction. For instance, when annual mean mortality rates are at 0.3 or 0.75, the exposed population would decline to the potential extinction level in about 270 or 30 years, respectively (Fig. 14).

4. Discussion

In this study, we used the survey information and published abalone growth models to estimate some crucial abalone population parameters. Based on the estimated size-specific proportion of cryptic abalone, mortality rates, and Beverton-Holt stock-recruitment curves, we examine the trajectories of abalone population growth and investigate impacts of mortality rates on the population growth. Current mortality rates abalone populations endure in QCI and CC are rather high, around 0.3 in QCI and around 0.35 in CC. The mortality rate estimated for abalone populations includes natural mortality rate and poaching-induced mortality rate. In review of abalone biology, Sloan and Breen (1988) reported that natural mortality rate for abalone populations is around 0.15-0.2. If the abalone populations in QCI and CC indeed have a natural mortality rate of 0.15-0.2, an approximate estimate of the poaching rate would be around 0.1. To restore the abalone populations, measures need to be taken to eliminate poaching and to reduce mortality rates down to 0.15-0.2.

The proportion of cryptic abalone is high for small abalone, declines quickly for medium sized abalone, and decreases slowly for large abalone. This sigmoid curve is well modelled using the generalized linear model with a binomial distribution error structure. This model enables us to estimate entire spawning stock biomass and recruits. The Beverton-Holt model appears to be a good stock-recruitment model for the abalone populations. The recruitment carrying capacity could be readily derived from the model, and was calculated to be $0.62/m^2$ for abalone populations in CC. Due to large variations in the stock and recruitment relationship and small range of available spawning stock biomass, the mathematically fitted Beverton-Holt curve for the stock-recruitment relationship in QCI does not appear to be biologically meaningful, as the resultant recruitment carrying capacity is too low. We assumed that the recruitment carrying capacity in QCI is the same as the estimated one in CC. The Beverton-Holt stock-recruitment curve fitted in this manner appears to be much more meaningful in the biological sense, and resembles the Beverton-Holt stock-recruitment curve in CC. The stock-recruitment models form the main engines for running population simulations. Comparisons of simulated densities with the observed ones seem to indicate that the established Beverton-Holt stock-recruitment models are reasonable. However, the recruitment carrying capacity in QCI possibly differs appreciably from the estimated one in CC. More stock and recruitment data, especially those containing larger spawning stock biomass, are needed to determine with more certainty the recruitment carrying capacity for abalone populations in QCI.

No age information is available for individual abalone. We used the established growth model with mean parameter values published to estimate the abundance of abalone at recruitment age (age 4) and to estimate mortality rates. Abalone in different habitats grow at different rates. Abalone in protected locations with high-quality food, such as *Macrocystis* and *Nereocystis* forests, grow faster and to a larger size than those in exposed places with low quality food, such as *Pterygophora* forests (Sloan and Breen 1988). Ideally, specific growth models should be applied for abalone populations in different habitats. However, the sample size for each sub-area was too small, and data had to be pooled together to apply the mean growth model. The amount of recruitment in each sub-area was then estimated based on the estimated proportion of abalone at recruitment age among the pooled data. Due to likely different growth rates, some biases or errors would inevitably be introduced in the estimations. Therefore, precaution needs to be taken in interpreting the modeling results.

5. References

Atkins, M, Lessard, J., and Campbell, A. 2004. Resurvey of northern abalone, *Haliotis kamtschatkana*, populations in southeast Queen Charlotte Islands, British Columbia, April, 2002. Can. Man. Rep. Fish. Aquat. Sci. 2704.

Boutillier, J.A., Carolsfeld, W., Breen, P.A., Farlinger, S. and Bates, K. 1985. Abalone resurvey in the southeast Queen Charlotte Islands, July 1984. Can. Manuscr. Rep. Fish. Aquat. Sci. 1818: 87 p.

Breen, P.A. 1986. Management of the British Columbia fishery for northern abalone (*Haliotis kamtschatkana*). Can. Spec. Publ. Fish. Aquat. Sci. 92: 300-312.

Breen, P.A. and Adkins, B.E. 1982. Observation of abalone on the north coast of British Columbia, July 1980. Can. MS Rep. Fish. Aquat. Sci. 1633: 55 p.

Campbell, A., Manley, I., and Carolsfeld, W. 1992. Size at maturity and fecundity of the abalone, *Haliotis kamtschatkana*, in northern British Columbia. Can Manuscr. Rep. Fish. Aquat. Sci. 2169: 47-65.

Carolsfeld, W., Farlinger, S., Kingzett, B.C., Sloan, N.A. and Thomas, G. 1988. Abalone resurvey in the southeast Queen Charlotte Islands, June 1987. Can. Manuscr. Rep. Fish. Aquat. Sci. 1966: 90 p.

Cripps, K., and Campbell, A. 1998. Survey of abalone populations at Dalain Point and Higgings Pass, Central Coast of British Columbia, 1995-96. Can. MS Rep. Fish. Aquat. Sci. 2445: 31 p.

Lessard, J., Atkins, M. J. and Campbell, A. 2007. Resurvey of northern abalone, Haliotis kamtschatkana, populations along the central coast of British Columbia, April 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2791: 35 p.

McCullagh, P. and Nelder, J.A. 1989. Generalized linear models, 2nd edn. Chapman and Hall.

Olsen, S. 1984. Shellfish enhancement report. NOAA, NMFS, Final report for project 1-144-R. Wash. State Dep. Fish., Seattle, Wash. 85 p.

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods, Eighth Edition. Iowa State University Press.

Pearce, C.M., Ågerup, P., Alabi, A., Renfrew, D., Rosser, J., Whyte, G., and Yuan, F. 2003. Recent progress in hatchery production of pinto abalone, *Haliotis kamtschatkana*, in British Columbia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 29-44.

Sloan, N.A., and Breen, P.A. 1988. Northern abalone, *Haliotis kamtschatkana*, in British Columbia: fisheries and synopsis of life history information. Can. Spec. Publ. Fish. Aquat. Sci. 103. 46 p.

Thomas, G., Farlinger, S., and Carolsfeld, W. 1990. Abalone resurvey in the southeast Queen Charlotte Islands in 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2099: 66-82.

Table 1. Number of sub areas and survey years in Queen Charlotte Island and Central Coast.

Queen Charlotte Island

Seven Sub Areas:

Carpenter Bay	Cumshewa Inlet	Kunghit Island	Juan Perez Sound
Selwyn Inlet	Skincuttle Inlet	Tanu Island	

Survey Years:

1978 1979 **1984** **1987** **1990** **1994** **1998** **2002**

Central Coast

Nine Sub Areas:

Lotbiniere Bay	North Aristazabal	North Banks Island	Oswald Bay
Pemberton Bay	South Aristazabal	Simonds	Spider Island
Striker Island			

Survey Years:

1978 **1979** 1980 **1983** **1985** **1989** **1993** **1997** **2001**

** Survey years in bold were used in the stock-recruitment studies.

Table 2. Estimated mortality rates and standard errors using two calculation methods for abalone populations in Queen Charlotte Island and Central Coast.

Method	Queen Charlotte Island	Central Coast
Forward	0.23 (0.042)	0.21 (0.064)
Backward	0.29 (0.046)	0.36 (0.065)

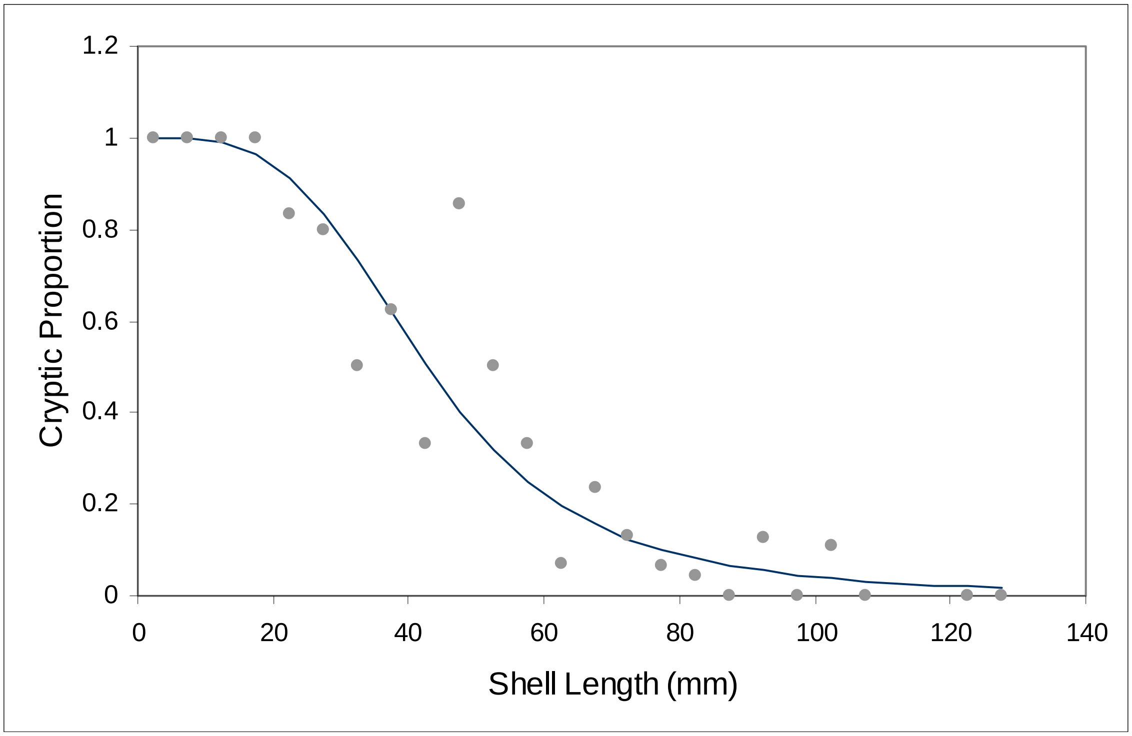
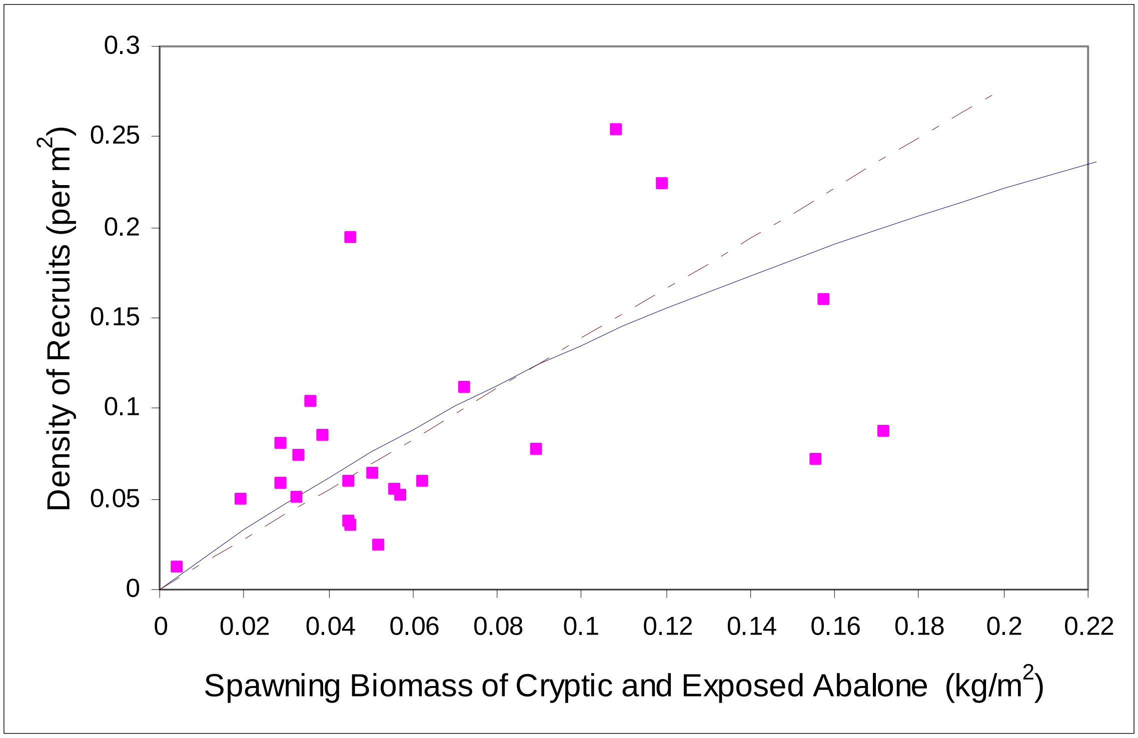


Figure 1. Proportion of cryptic abalone in Queen Charlotte Island at shell length.



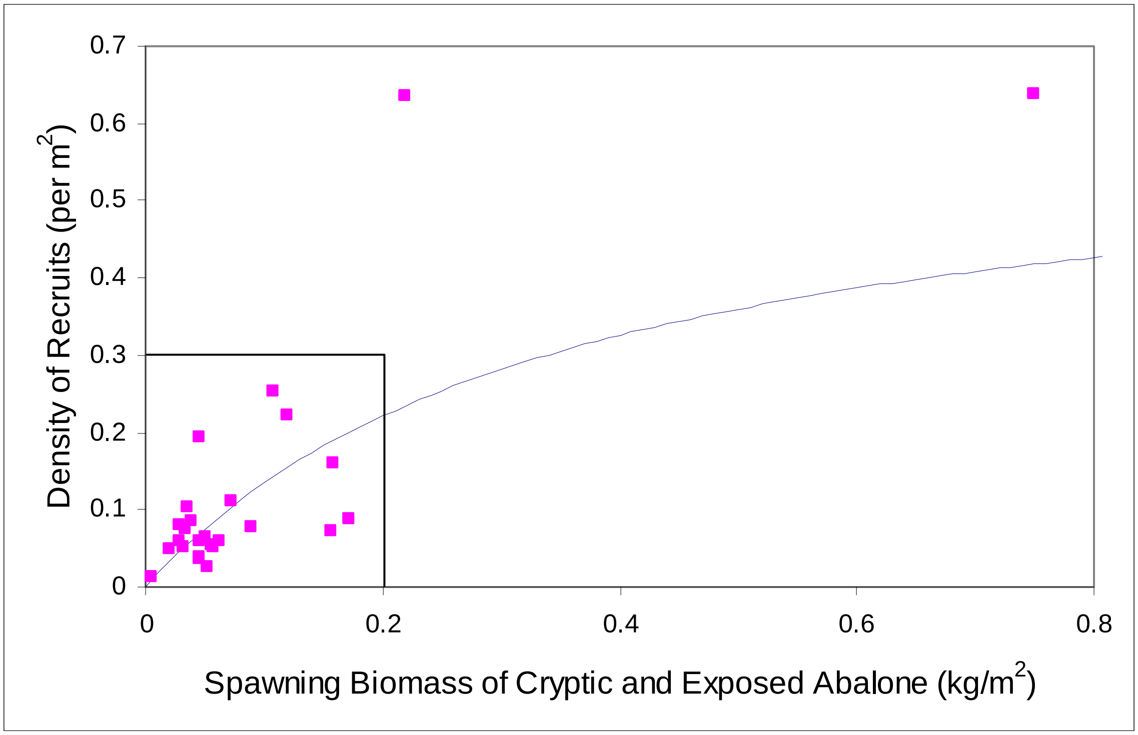


Figure 2. Stock recruitment models for abalone in Central Coast. The solid line is the Beverton-Holt curve, and the broken line is the density-independent curve. (Recruitment is represented by the density of both cryptic and exposed abalone at age 4).

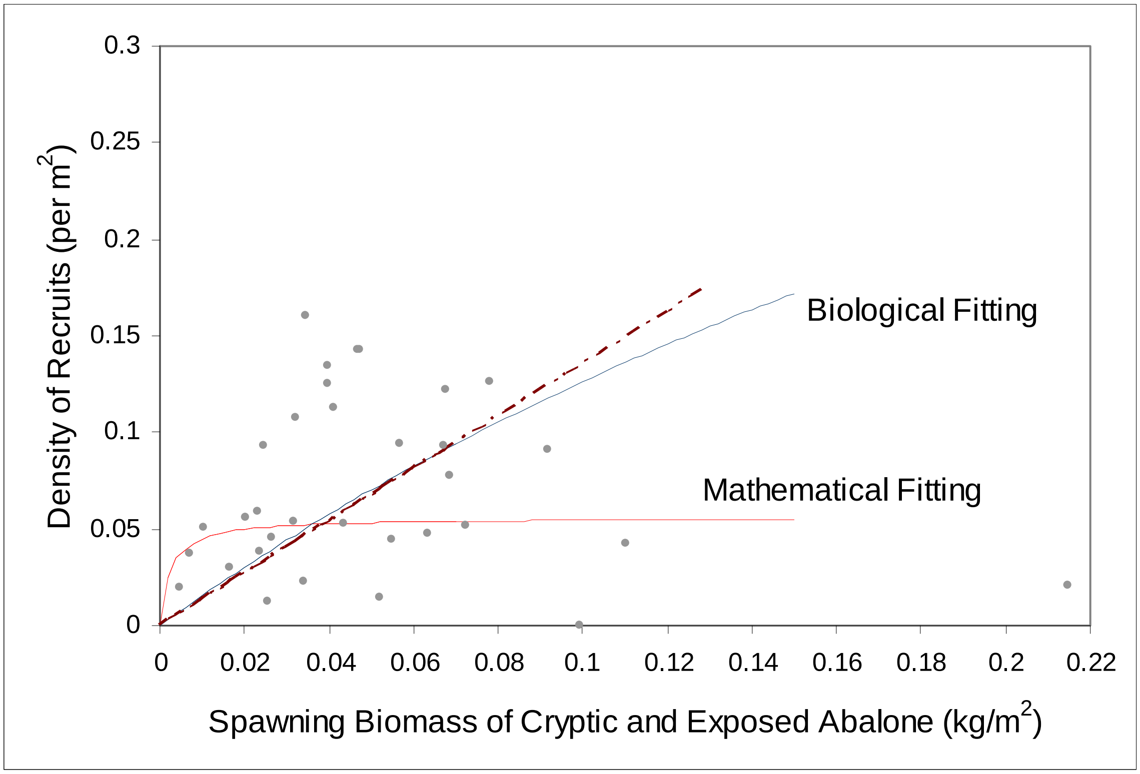


Figure 3. Stock recruitment model for abalone in Queen Charlotte Island. The solid lines are the Beverton-Holt curves, and the broken line is the density-independent curve. (Recruitment is represented by the density of both cryptic and exposed abalone at age 4).

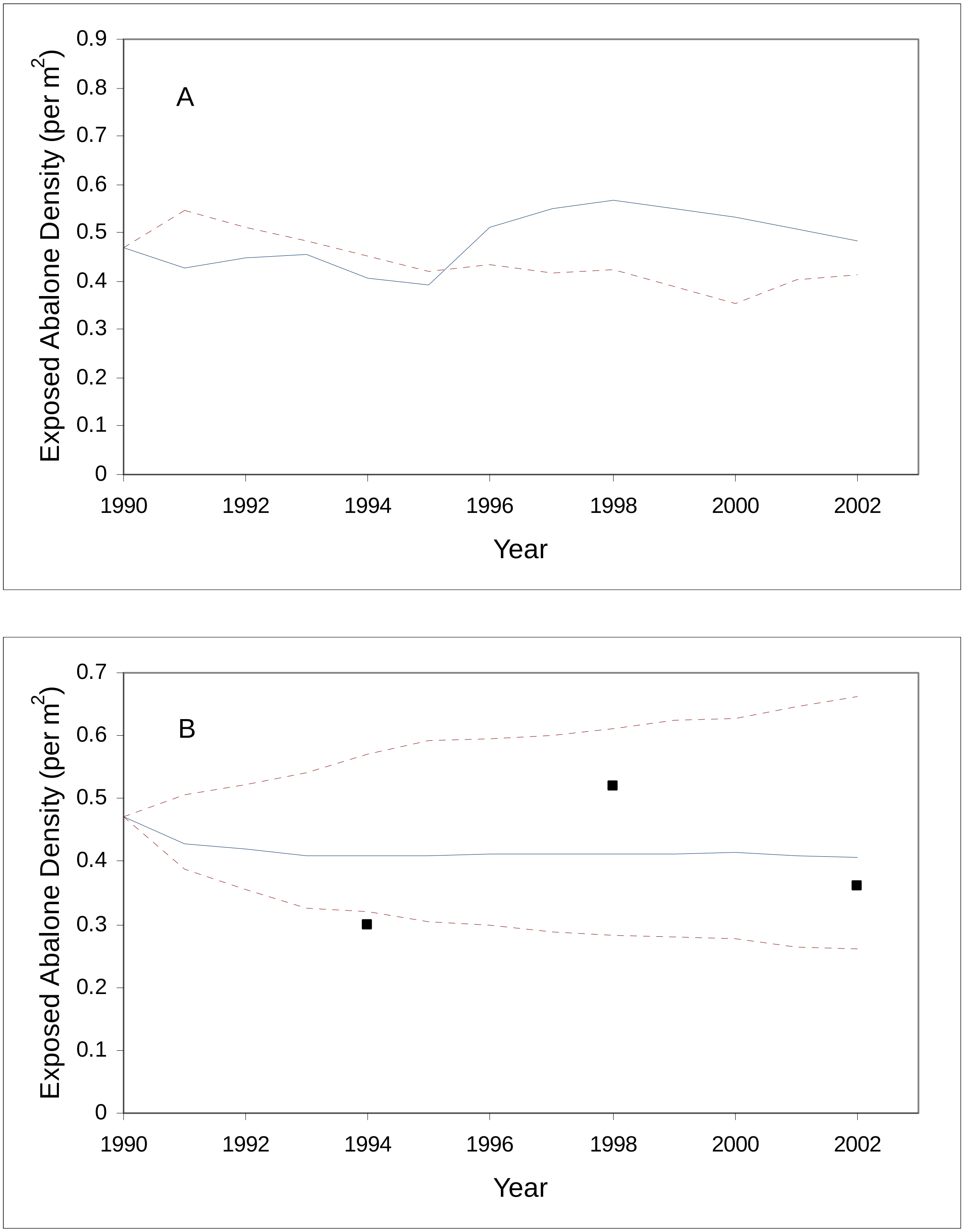
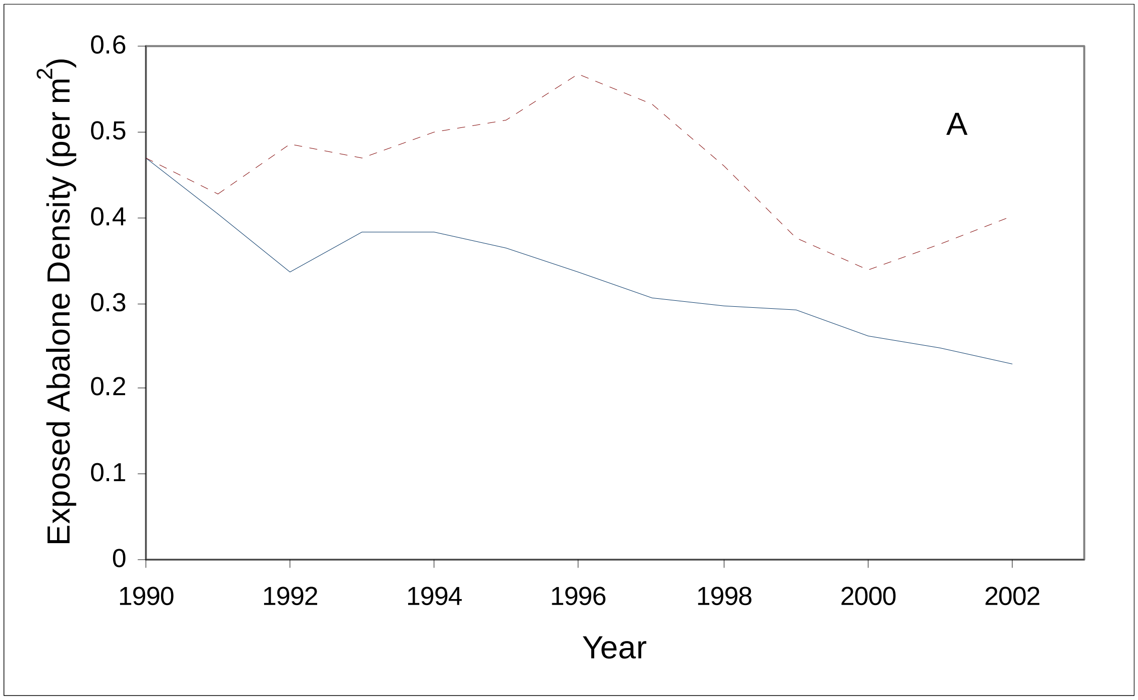


Figure 4. Comparison of simulated and observed densities of exposed abalone in Queen Charlotte Island. The simulation starts from 1990 with a mortality rate of 0.23.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.
■ – Observed mean density of exposed abalone in the surveys.



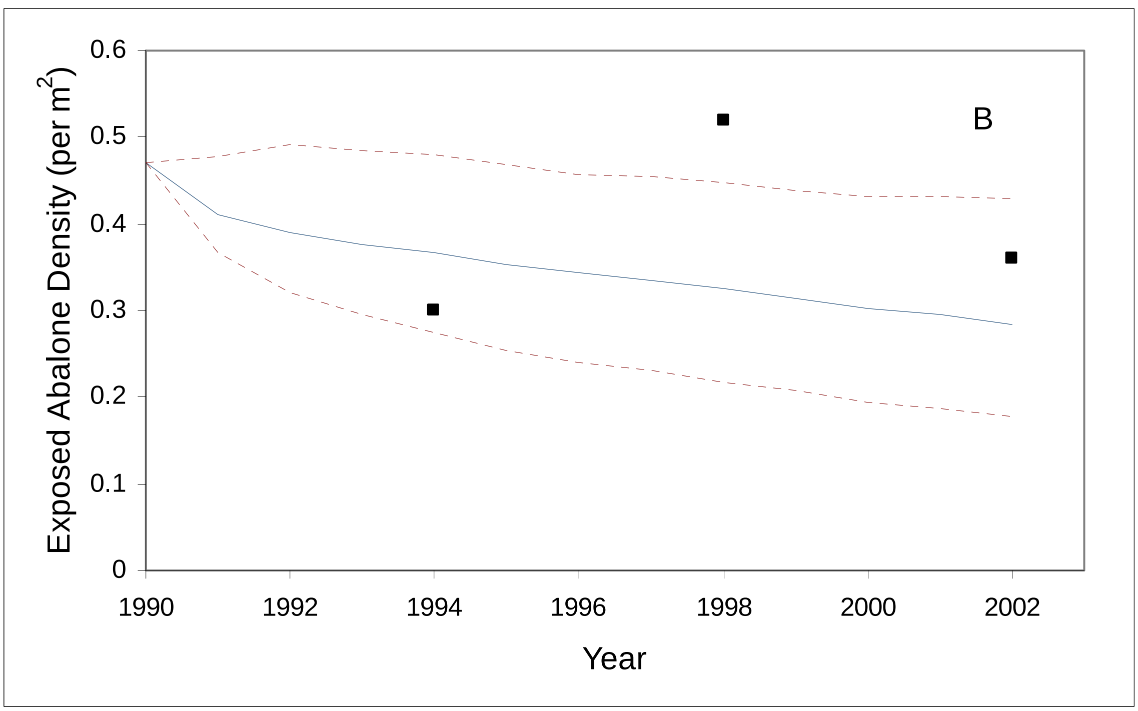


Figure 5. Comparison of simulated and observed densities of exposed abalone in Queen Charlotte Island. The simulation starts from 1990 with a mortality rate of 0.29.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.
■ – Observed mean density of exposed abalone in the surveys.

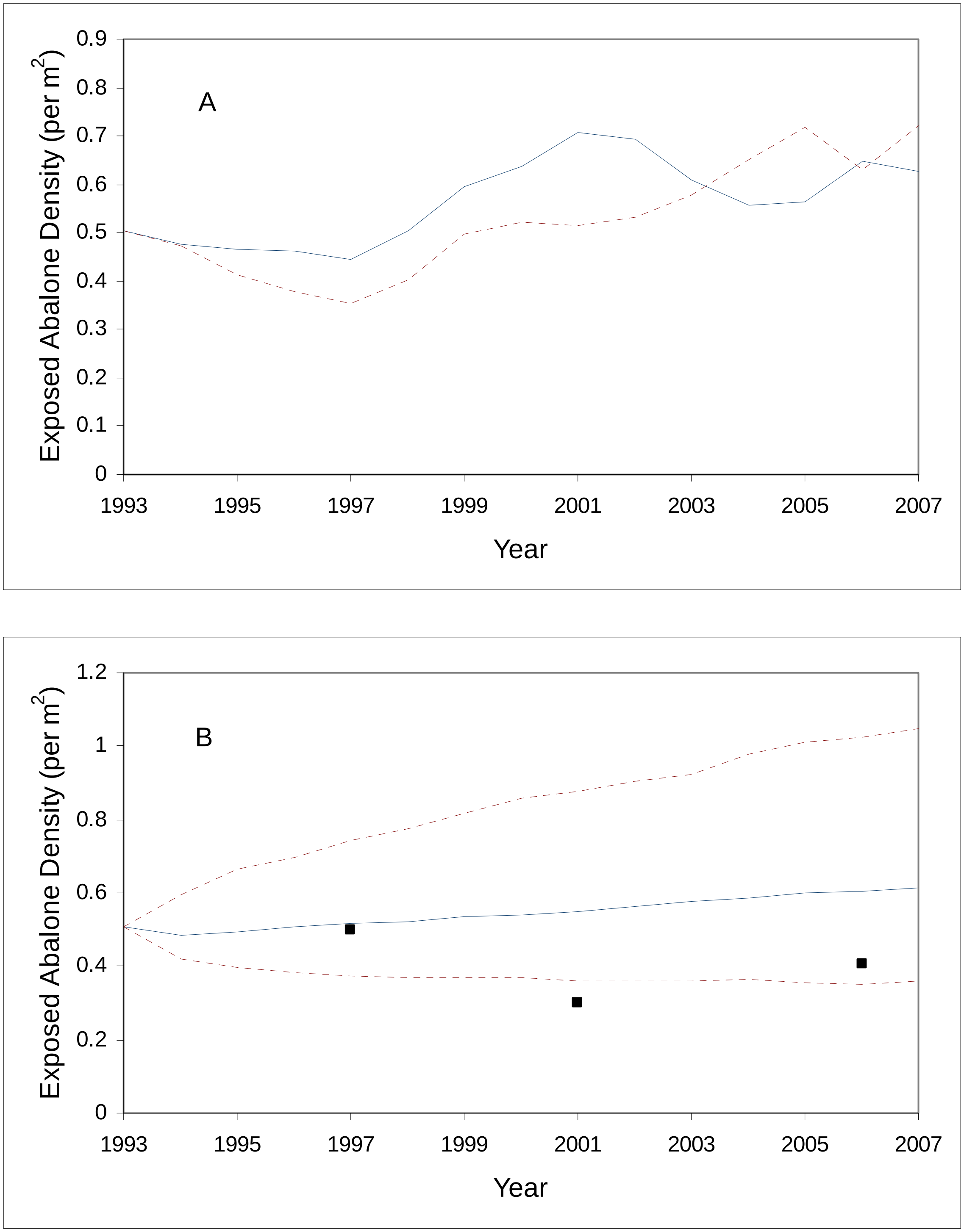


Figure 6. Comparison of simulated and observed densities of exposed abalone in Central Coast. The simulation starts from 1993 with a mortality rate of 0.21.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.
■ – Observed mean density of exposed abalone in the surveys.

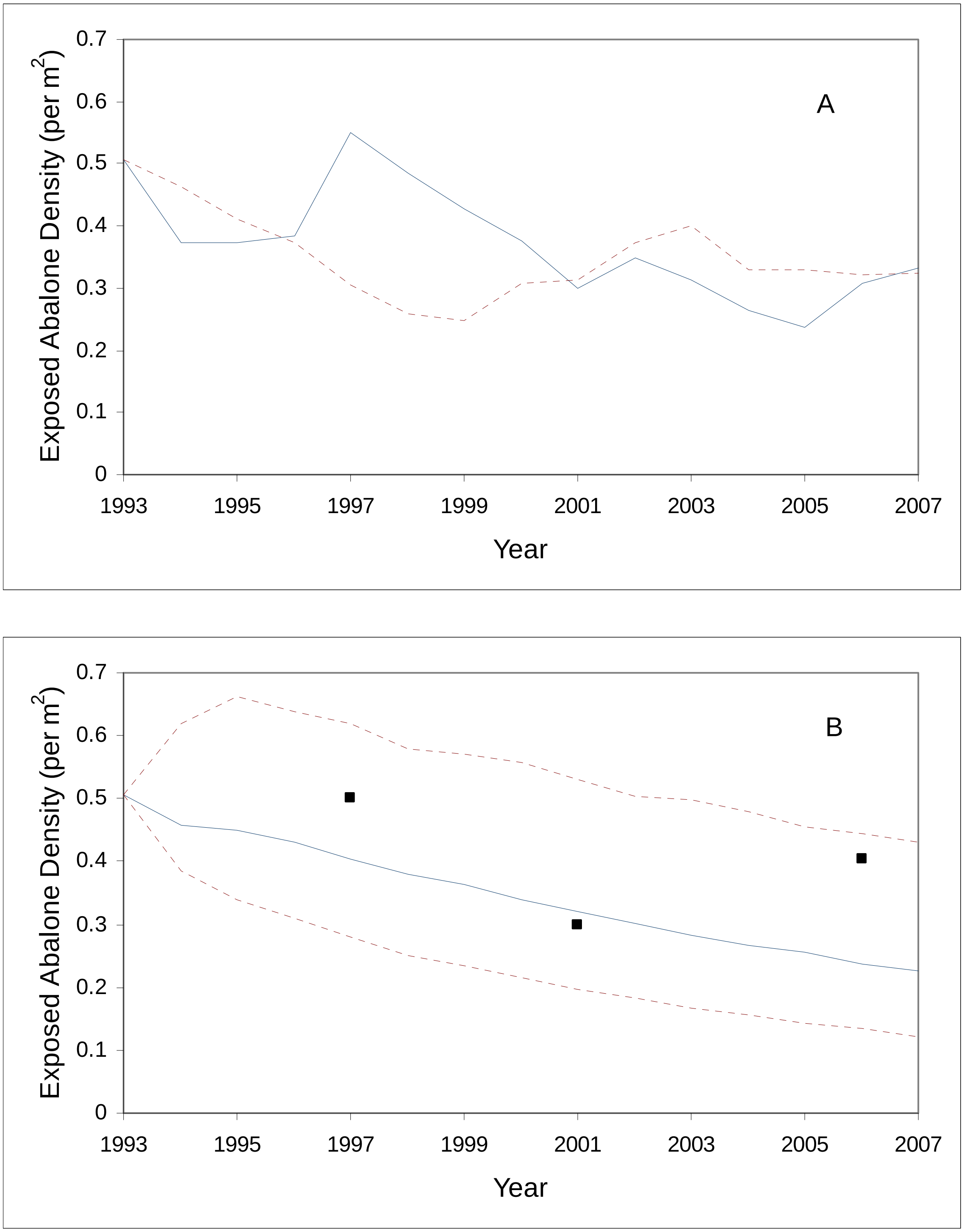
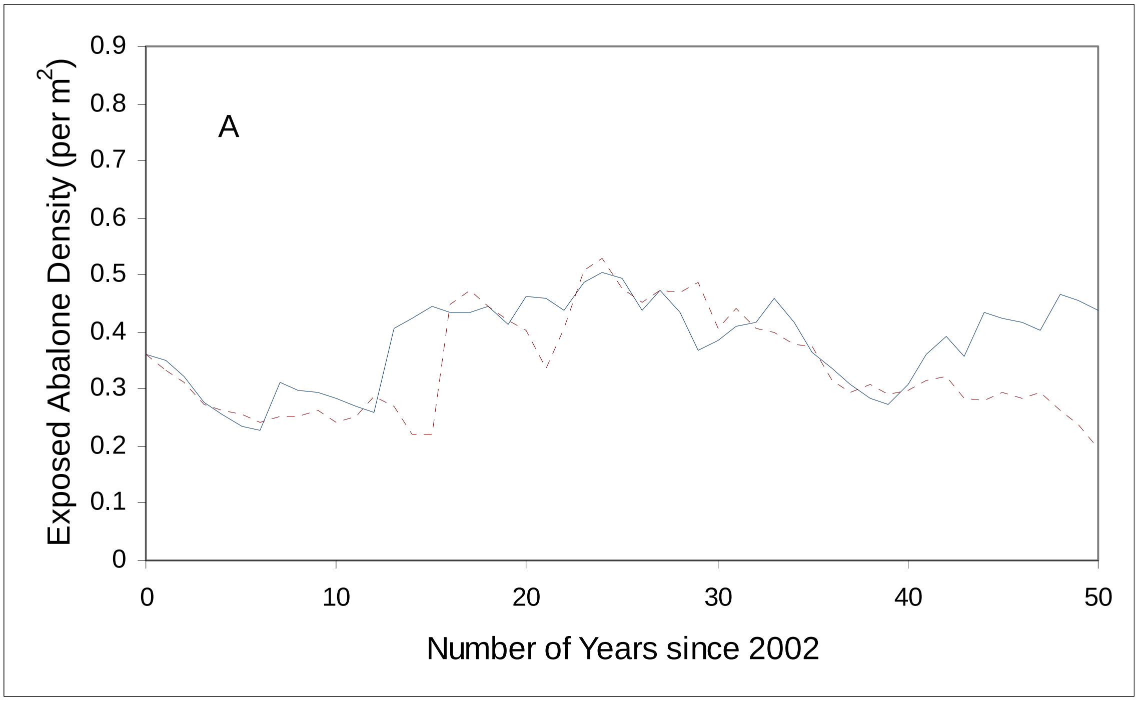


Figure 7. Comparison of simulated and observed densities of exposed abalone in Central Coast. The simulation starts from 1993 with a mortality rate of 0.36.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.
■ – Observed mean density of exposed abalone in the surveys.



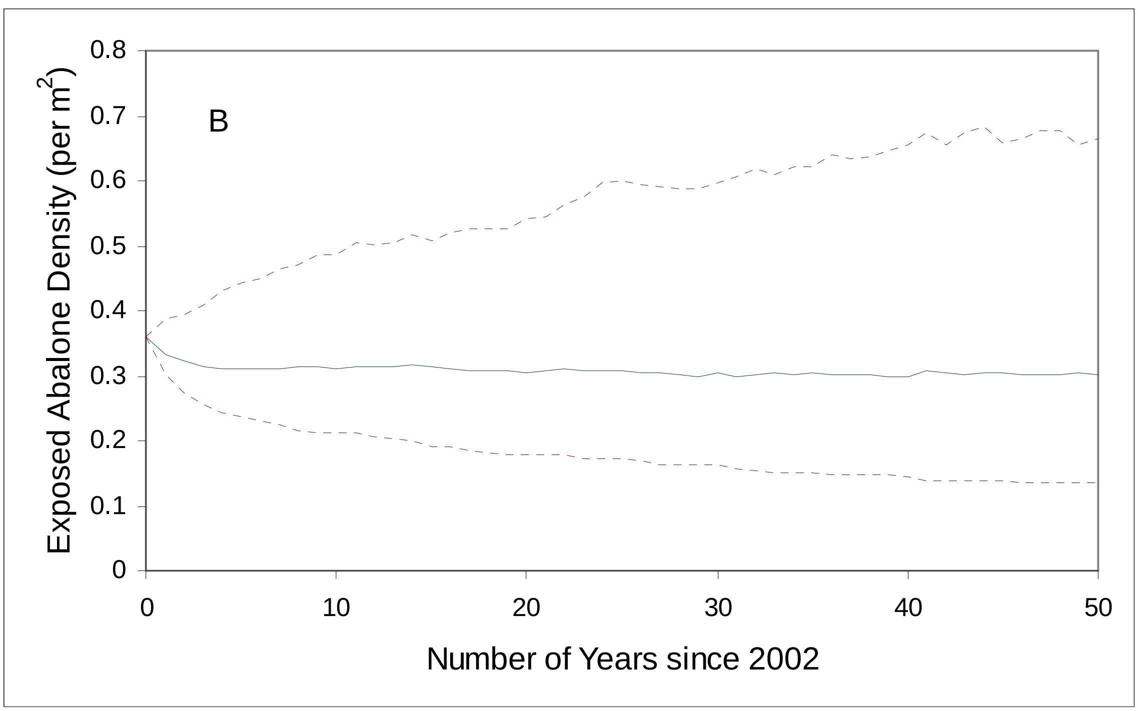
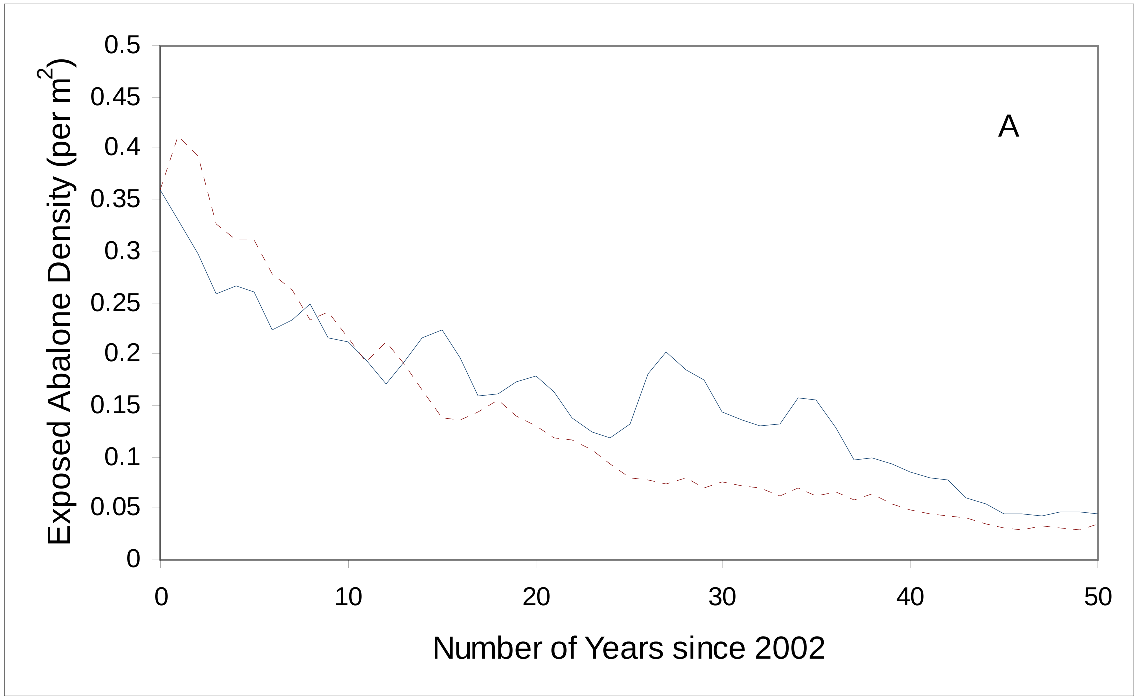


Figure 8. Simulated densities of exposed abalone in Queen Charlotte Island. The simulation starts from 2002 with a mortality rate of 0.23.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.



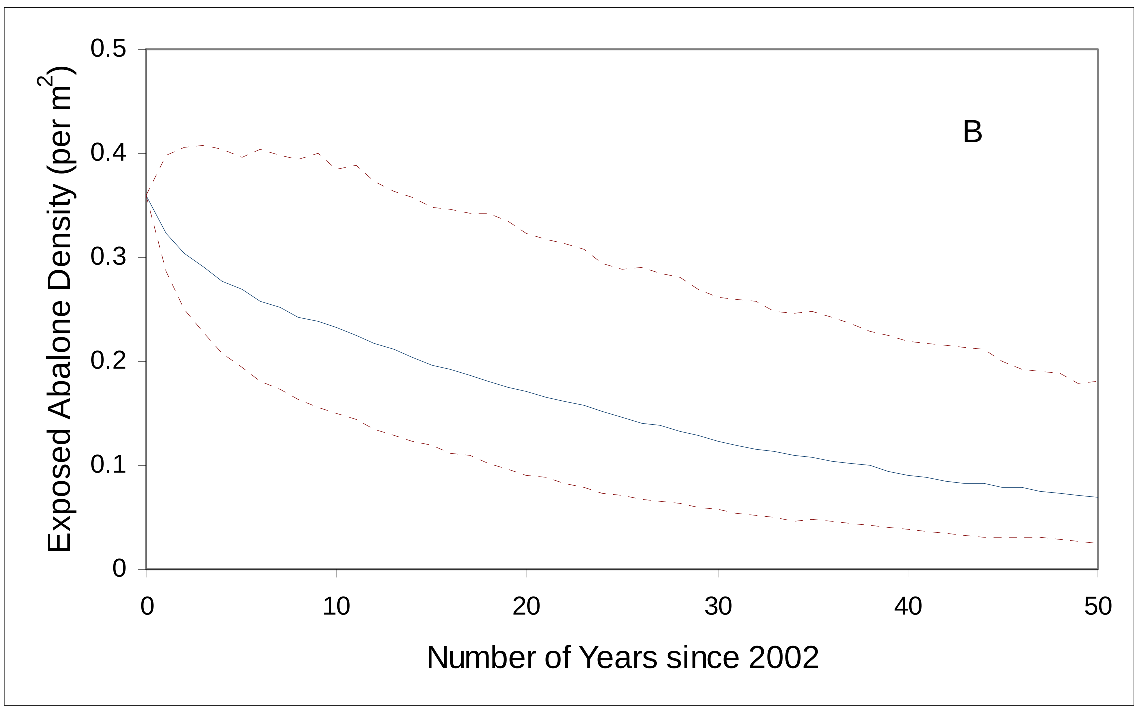
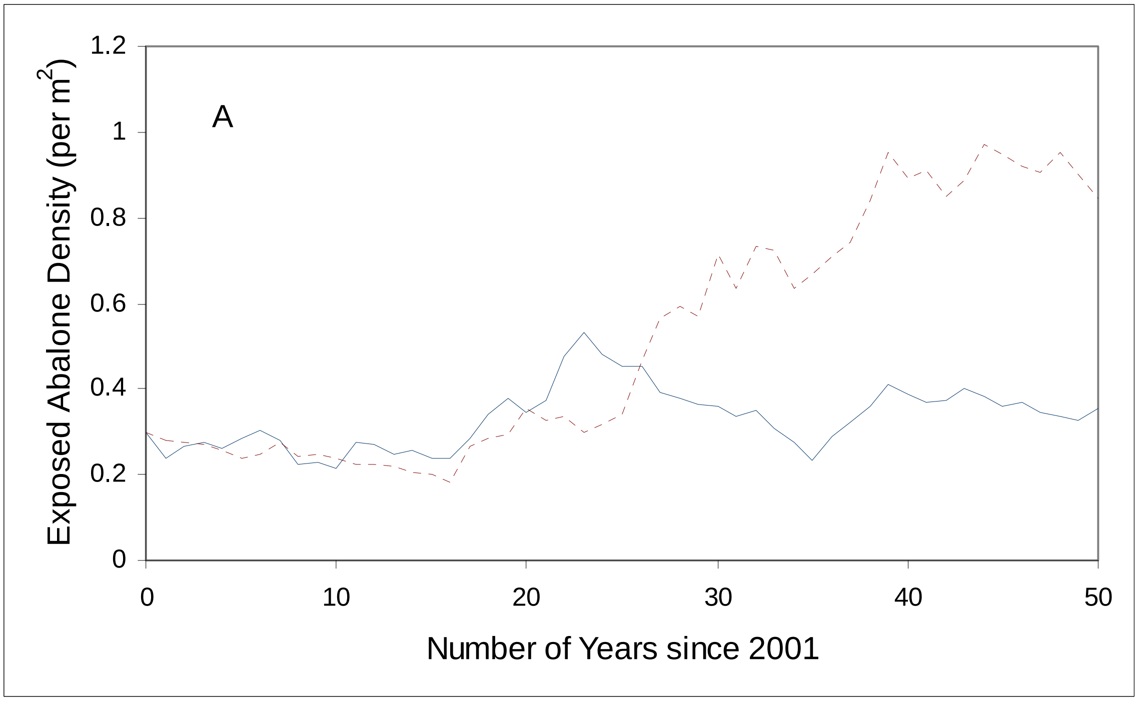


Figure 9. Simulated densities of exposed abalone in Queen Charlotte Island. The simulation starts from 2002 with a mortality rate of 0.29.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.



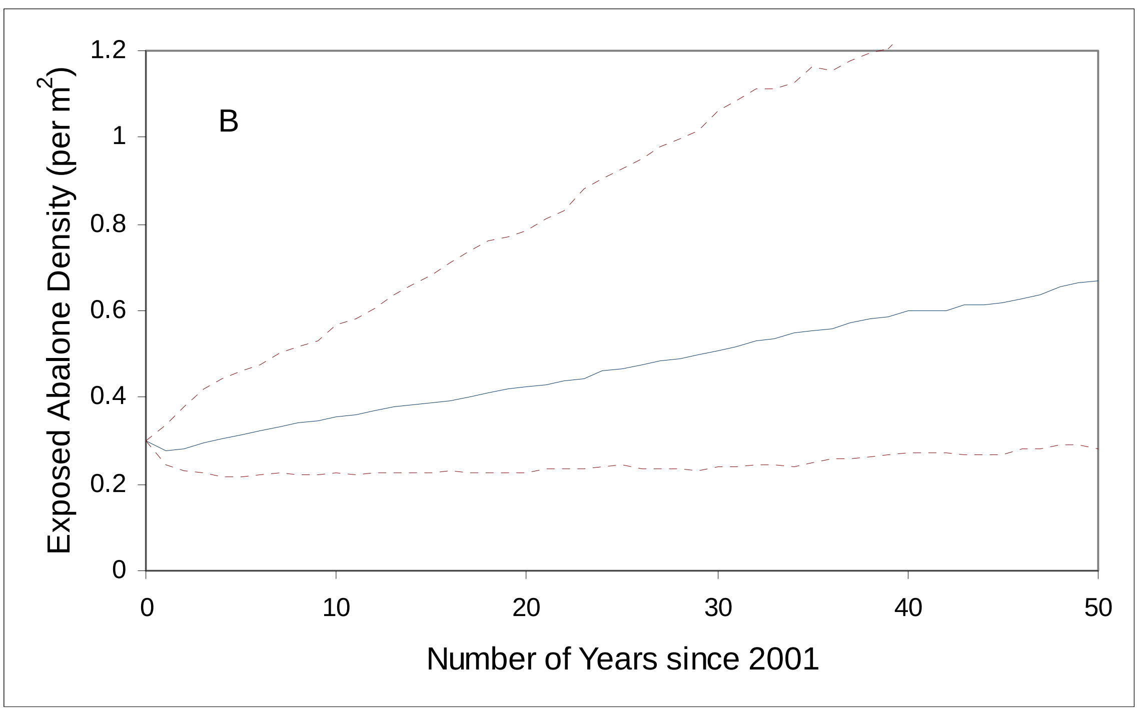
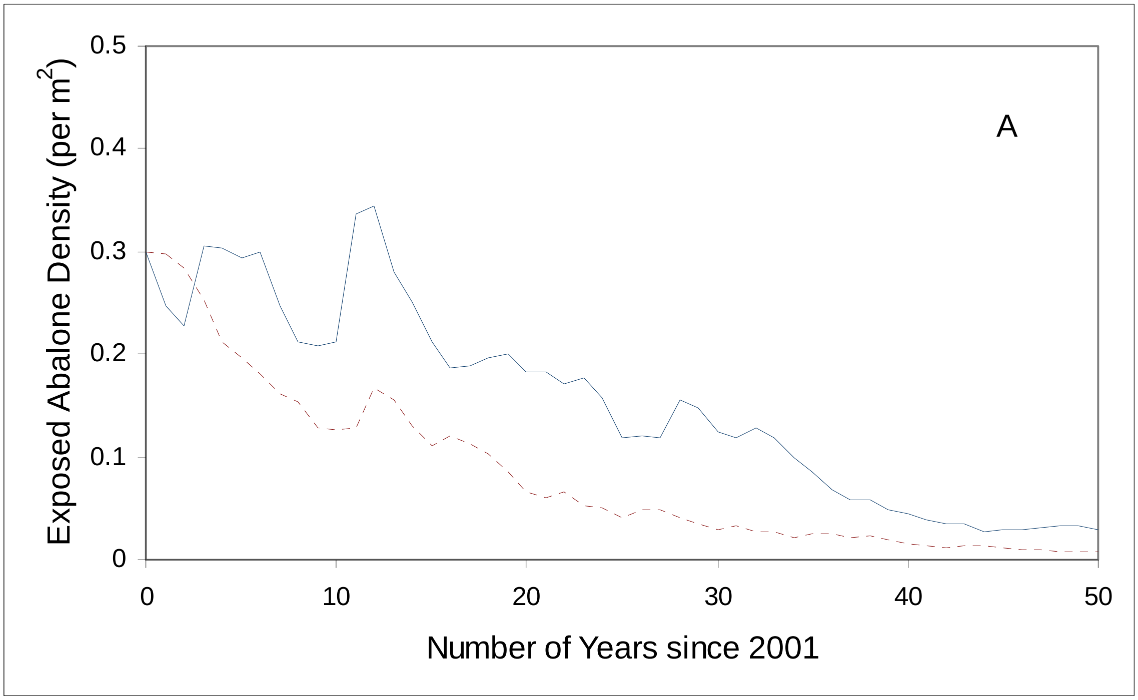


Figure 10. Simulated densities of exposed abalone in Central Coast. The simulation starts from 2001 with a mortality rate of 0.21.
A – Two randomly chosen simulated trajectories.
B – Mean and 95% confidence intervals.



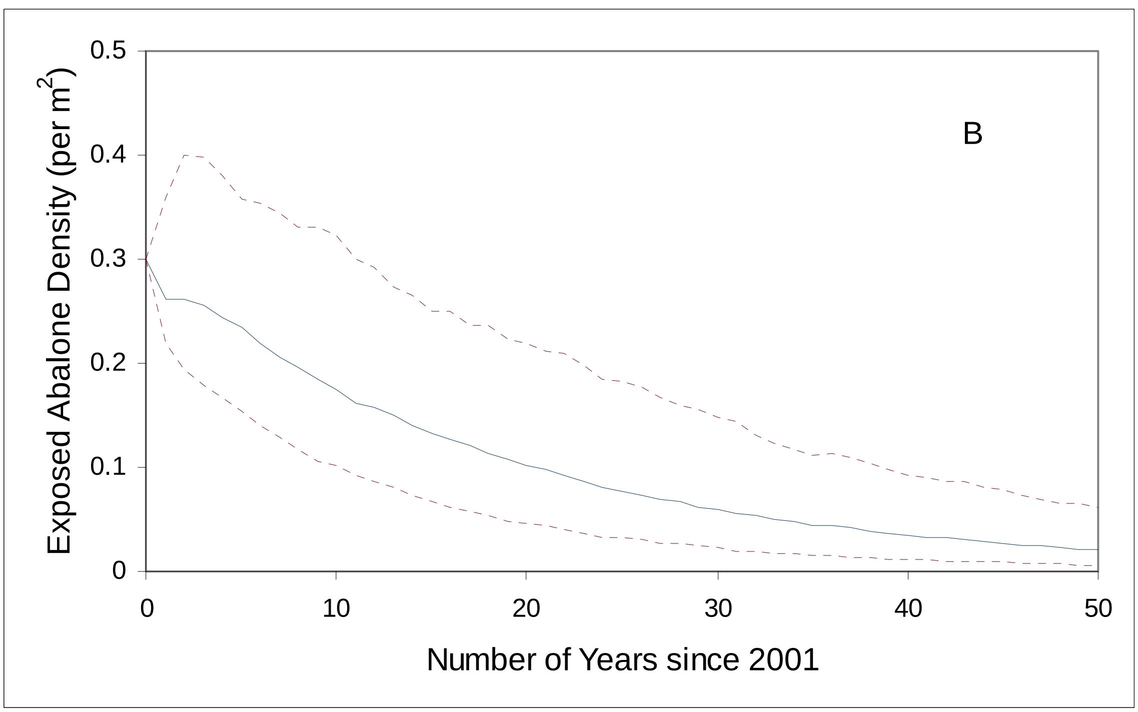


Figure 11. Simulated densities of exposed abalone in Central Coast. The simulation starts from 2001 with a mortality rate of 0.36.
A – Two randomly chosen simulated trajectories.
B – Mean and 90% confidence intervals.

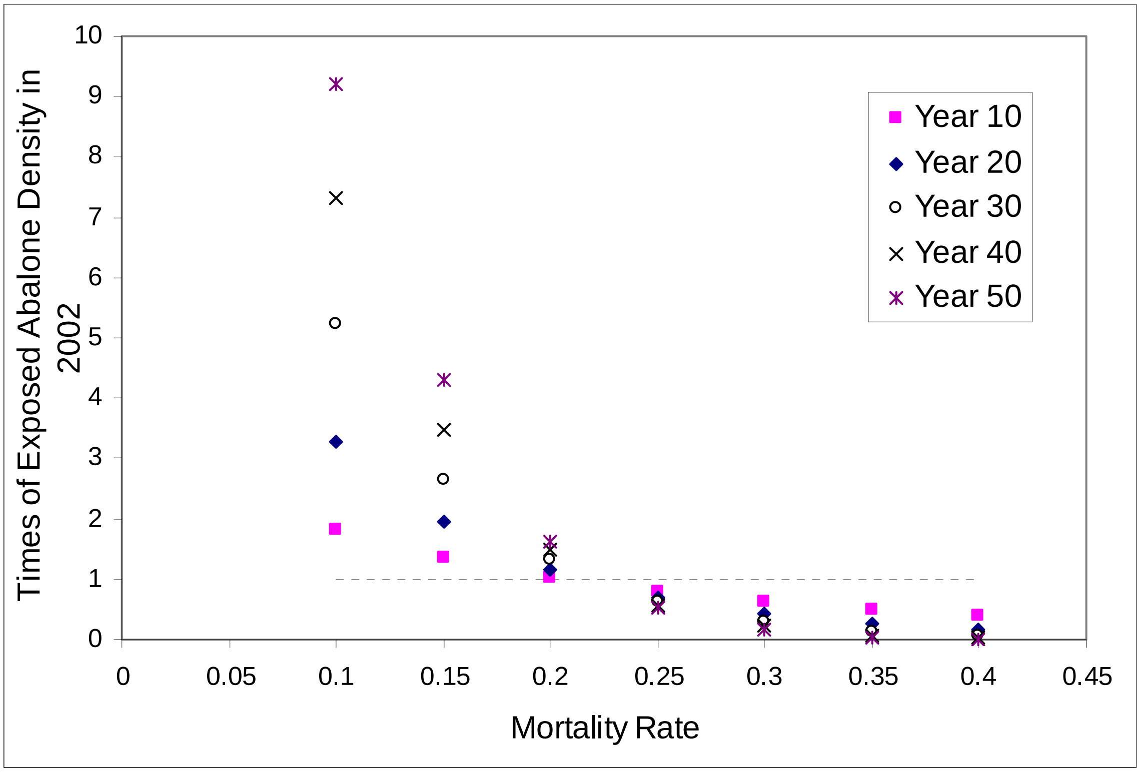


Figure 12. Expected changes in the density of exposed abalone relative to the observed mean density in 2002 in Queen Charlotte Island with different annual mortality rates and number of years after 2002. The dotted line indicates the level at which there is no change in population density relative to the current density.

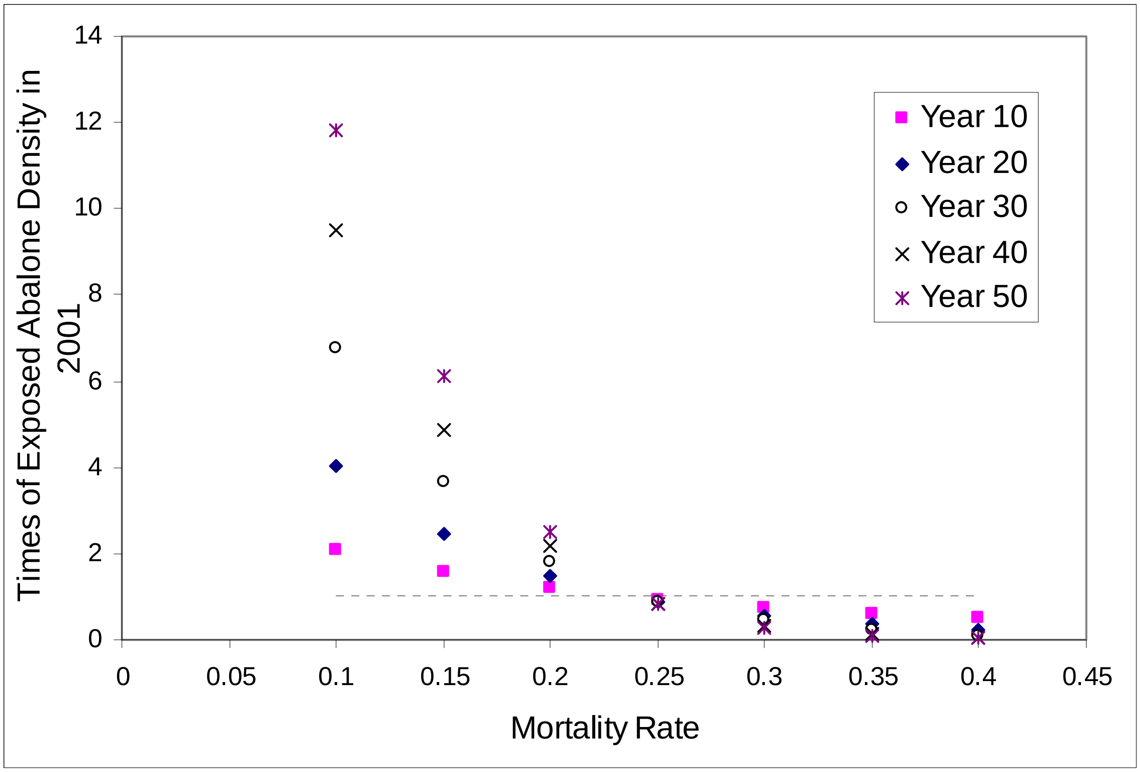


Figure 13. Expected changes in the density of exposed abalone relative to the observed mean density in 2001 in Central Coast with different annual mortality rates and number of years after 2001. The dotted line indicates the level at which there is no change in population density relative to the current density.

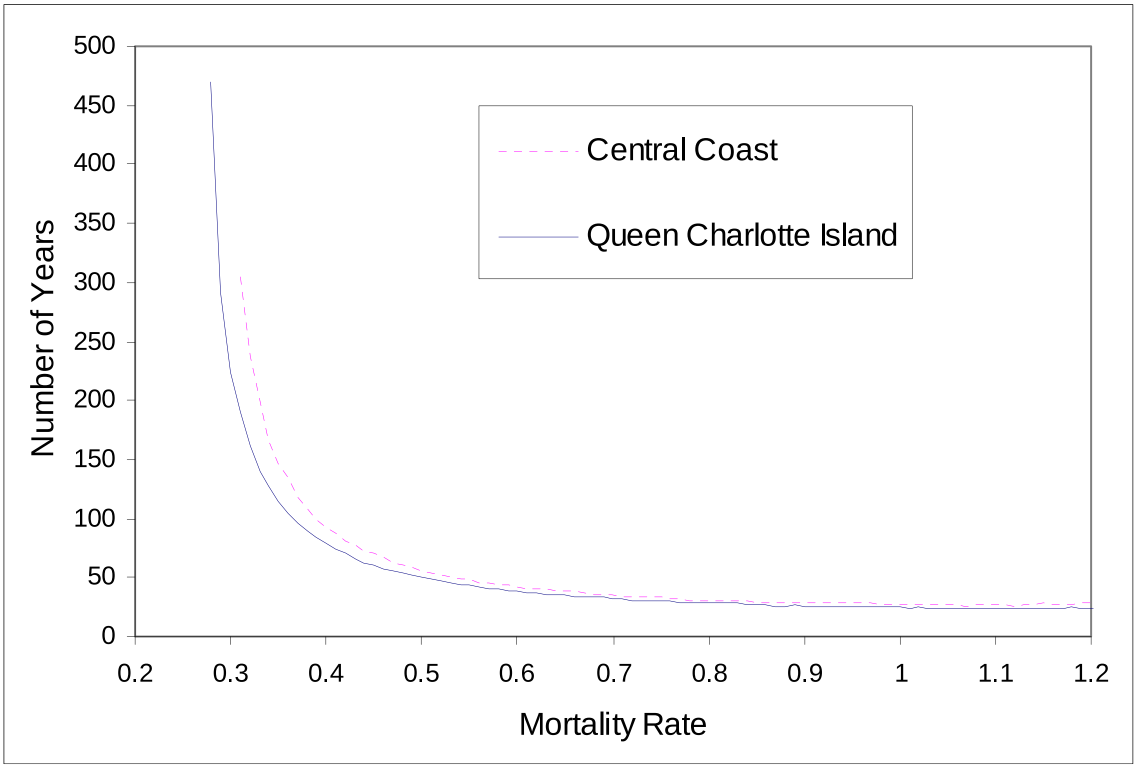


Figure 14. Expected number of years for simulated exposed abalone populations (all sizes combined) to reach $0.001/m^2$ (or to approach potentially extinction) under different annual mortality rates in southeast Queen Charlotte Islands and Central Coast.

Appendix 2 Impact assessment protocol for works and developments potentially affecting abalone and their habitat

Impact assessment protocol for works and developments potentially affecting abalone and their habitat

by

Joanne Lessard
Alan Campbell

Table of Content

1. Definitions

3rd PARTY BIOLOGIST: an established independent third party biological consultant company or an independent third party biologist accredited with a university or college degree in a related biological science that has preferably formed an independent company under his/her own name with experience working with DFO in accomplishing biological research including surveys. Other requirements are outlined in Appendix A.

ABALONE HABITAT: description of physical and biological features of habitats where abalone are found; includes all abalone habitats as well as critical (not defined for abalone). See Section 5.

CONTROL SITE: location outside of the area of influence and within 1000m of the potentially impacted site to minimize differences in current and temperature regimes

CRITICAL HABITAT: the habitat that is necessary for the survival or recovery of a listed wildlife species that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species (as defined under SARA)

IMPACT: unless other wise stated (e.g. impact on habitat) in this document, for the sake of brevity, impact refers to the direct or indirect impacts of works and developments on abalone abundance and distribution only.

INITIAL SURVEY: See Section 4.

MONITORING PROGRAM: the plot survey repeated at least once a year.

PLOT SURVEY: See Section 8.

PRECAUTIONARY APPROACH: Set of measures taken to implement the Precautionary principle. A set of agreed cost-effective measures and actions, including future courses of action, which ensures prudent foresight, reduces or avoids risk to the resource, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of being wrong. (Garcia S.M. (1996) The precautionary approach to fisheries and its implications for fishery research, technology and management: An updated review. FAO Fish. Tech. Paper, 350.2: 1-76)

RECRUITMENT: for this document, juvenile abalone with a shell length <70 mm.

SARA: Species at Risk Act

SITE: proposed site, unless otherwise stated (e.g. control site).

SL: Shell length, the maximum measurement of an abalone shell.

TRANSECT SURVEY: See Section 6.

2. Background

The provisions of SARA that were implemented on June 1, 2004 include:

- prohibitions on killing, harming, harassing, possessing, buying or selling an individual of a species listed as an extirpated species, an endangered species or a threatened species etc. (section 32).

- prohibitions on damaging or destroying residences of individuals (section 33).
- prohibitions on destroying the critical habitat of a listed endangered or threatened species or listed extirpated species (section 58).
- provisions for effective enforcement measures and significant penalties where needed to serve as a deterrent.

These prohibitions will apply to aquatic species that are listed under SARA as extirpated, endangered or threatened. There is a provision in SARA (section 73) that allows the competent minister (DFO for listed aquatic species) to authorise a person to engage in an activity that affects a listed wildlife species, its critical habitat or residence. However, this provision also includes a series of strict criteria that must be met prior to doing so.

Currently there is ample habitat available in BC for the northern abalone population. In general, abalone populations have declined; however, there has been no known significant reduction in available habitat. Therefore, habitat loss is not a major concern in the recovery of northern abalone at this time in comparison with the identified threats. Although good abalone habitat is not believed to be limiting, there may be certain habitat where juvenile survival is better, or where the reproducing adults contribute to a larger portion of the total recruitment. Identification of this key habitat is being included as part of the abalone research and rebuilding plans.

The abalone recovery strategy identified several knowledge gaps (Abalone Recovery Team 2002). The recovery strategy identified the need to clarify the extent of threat of works and developments on, in and under the water to northern abalone populations and habitat. The recovery strategy also identified the need for monitoring and regulation of projects to prevent losses to important spawning aggregations and maintain ecosystems in which abalone can recover. Once 'critical habitat' for northern abalone is defined (e.g., abalone beds or important spawning aggregations), specific criteria to protect it under the Fisheries Act and Regulations (1993) and SARA (2003) may be better developed and applied. Until then, it is recommended that the best science available be used, and where science is lacking that a precautionary approach be adopted in considering and approving location(s) for works and developments on, in, and under the water.

Determining impacts on a site by site basis is impractical and will not provide meaningful data as other factors may affect abalone populations. However, when all sites with abalone are combined it may be possible to determine the impact(s) if a proper scientific method is followed. It is the intention of the monitoring program described in Section 8 to evaluate what these impacts are. Given DFO abalone stock assessment limited budget, no large scale studies are planned to determine the impacts of works and developments on, in or under the water on abalone populations. Therefore, the proponents will have to either pay for a DFO certified 3rd party biologist and/or give money to DFO to carry out the work, which will include field survey, analysis and reporting.

This impact assessment protocol applies to any proposed works and developments where abalone habitat is present and the area affected will be larger than $20m^2$. The amount of abalone habitat necessary to trigger this protocol is arbitrary and is purposely small as the shape of the area impacted is important. For example, $20m^2$ distributed as a 1m vertical swath to a depth of 10m with a moderate slope is not equal to 20m wide 1m horizontal swath parallel to shore at 3m depth because abalone prefer shallow depths and more abalone preferred habitat is impacted in the second scenario. If abalone are present in a small area (i.e. $<20m^2$) expected to be impacted, the individual abalone shall be relocated, under a SARA permit, to suitable abalone habitat nearby. The SARA permit will include the following conditions (some conditions may vary depending on the available abalone habitat nearby):

1. The dive surveys of the area to be impacted must take place at night and search successive depth contours in a systematic and thorough manner.
2. All abalone observed within the survey area must be removed from the substrate by hand only, with the assistance of a *Pycnopodia helianthoides* (sunflower sea star) if necessary; prying abalone from the substrate is not permitted;
3. The shell length (to the nearest mm), depth located, substrate type and dominant algae species must be recorded for each abalone observed;
4. The abalone must be relocated underwater to a location of cover in rocky subtidal habitat no deeper than 6m depth (chart datum) and a minimum of 50 metres away from the construction footprint; taking abalone from the water is not permitted;
5. Plastic totes may be used to move the abalone underwater and abalone may be relocated in close proximity of another abalone to improve chance of spawning success;
6. As a requirement to report information under this project, the authorized persons must submit a written record containing the following summary information:
   i. Dates in which relocation surveys took place;
   ii. Number of abalone observed and relocated;
   iii. Shell length, depth located, substrate type and dominant algae cover for each abalone observed;
   iv. Overall perspective on the success or difficulties in conducting the work.

3. How to determine impact on abalone

Except for surveyed sites, there is a general lack of data on abalone distribution and abundance throughout the BC coastline. Site specific information for proposed works and developments must be acquired before any decision can be made. In order to determine impacts of works and developments on abalone populations and make inference to their habitat, abalone will have to be present at some sites. Only abundance, and possibly distribution, data will be used to determine impacts in the short term (2-5 years) as other parameters of abalone population health are more difficult to measure (e.g. change in reproductive output, growth, disease incidence, etc.). Impacts may be determined by changes in density before and after the project is completed in conjunction with the continuous monitoring of control site(s) outside of the area of influence. For example, there may be a statistically significant changes (increases or decreases) in total abalone density within the site, but no change at the control site(s) or the total density does not change, but one of size category (juvenile, mature, etc.) becomes more dominant when compared with the control site(s). Observing changes in abalone spatial distribution will be more difficult unless some animals are uniquely identified (tagged), particularly if density decreases and few or no shells are recovered. Nevertheless, changes in depth distribution and aggregation will be possible under the proposed monitoring approach described in Section 8.

To obtain information necessary to make a decision on the site and evaluate impacts if approved, we recommend a four phased approach:

- Phase 1: Initial Survey

The site is assessed to determine the extent of abalone habitat present using nearshore swims. The abalone habitat is then mapped.

- Phase 2: Transect Survey

  A quantitative survey is conducted to estimate abalone densities within the abalone habitat identified in Phase 1 as well as in an area outside the area of influence.

- Phase 3: Monitoring program – Plot survey

  If the site is accepted and abalone are present, an intensive survey is conducted at 1-3 plots within the impacted site as well as within a control site, outside the area of influence.

- Phase 4: Feed Back

  After 5 years, an analysis of abalone abundance and distribution data combining several sites of a given type of work or development should be completed to evaluate the impacts and determine if mitigation actions are required.

Each phase is described in detail in the sections below. We recommend that Phase 1 to 3, if not done by DFO staff, be completed by a certified 3rd party biologist (see Appendix A for requirements).

4. Phase 1: Initial Survey

The objectives of this phase are to (1) establish the area of Abalone Habitat present at the site, and (2) delineate these habitats on a chart. Although all habitats are important, for the purpose of this document, only abalone habitat is described in Section 5.

Site definition

The site is defined by using landmarks and geographic coordinates. The 'site width' is the linear distance between the two furthest points.

Nearshore-swims

Two divers swim (a few metres apart from each other) in a zigzag pattern (generally parallel to shore) between depths of 0-10 m chart datum. Very good notes need to be taken throughout the swim so that the GPS coordinates can be related to what was observed underwater. Habitat changes including changes in primary substrate (e.g., bedrock to boulders or sand), and algal community (e.g., from a *Macrocystis* to a *Nereocystis* kelp forest or understorey algae only), should be marked using one of two methods described below.

Method 1: Floats can be deployed at the edges of each change in habitat. The boat can then use a GPS to obtain the coordinates. Because the edges of habitats do not usually form a straight line, several floats need to be release to accurately map the habitats.

Method 2: One person is put on shore at a location where most of the surface water of the site would be visible and records his/her position using a portable GPS. Two divers swim throughout the site during several dives carrying a metal float. At a change in habitat, one of the divers pulls on the float several times while the other diver records the time, depth and other habitat information. Upon seeing the float bob at the surface, the shore person measures the distance to the float using a laser range finder and the magnetic bearing of the float using a compass and records the time which will be matched with the time recorded underwater.

Desired results

The end product of this phase should be a digital map with depth contours and the important habitats delineated. Although all habitats should be outlined, for the purpose of this document, only abalone habitat is described here in detail (see next section).

Data Management

The GPS shore positions are imported into ArcView 3.2 or another GIS software.

Method 1: The GPS positions from the boat are matched with the divers notes to digitize (create a polygon) abalone habitat.

Method 2: From the shore positions, the measured distances and bearings are plotted using an extension from Jenness Enterprises called "Distance & Azimuth tool" (http://www.jennessent.com/arcview/arcview_extensions.htm). Polygons delineating abalone habitat are created using the plotted positions.

The digital map, electronic file containing the GPS points and copies of the field notes must be sent to the Shellfish Data Unit, PBS, Nanaimo.

Decision rule for next step

If abalone habitat, as described in the next section, is present and the area of the abalone habitat is > $20m^2$, then the next phase is necessary to assess the abalone density at the site as well as in surrounding areas.

5. Abalone Habitat

Physical factors include:

i. Primary Substrate: bedrock and/or boulders
ii. normal salinity (not low salinity as found close to river run off)
iii. Depth: ≤10m depth (datum)
iv. Good water exchange (tidal current or wave action present)
v. Secondary Substrate: some cobble may be present and little or no gravel, sediment, sand, mud, or shell present.

Biological factors include:

i. Presence of encrusting coralline algae (e.g. *Lithothamnium*)
ii. Presence of sea urchins *Strongylocentrotus franciscanus* and/or *S. droebachiensis, Lithopoma (Astraea) gibberosa*, sea stars.
iii. Presence of kelp in surrounding area (e.g., *Nereocystis, Macrocystis, Pterygophora*).
iv. Presence/absence of abalone

Physical and biological factors are listed in order of importance.

6. Phase 2: Transect survey

The objective of the transect survey is to get quantitative estimates of abalone density and distribution within the abalone habitat delineated in the initial survey (Phase 1). This is necessary to evaluate if the work or development proposal will be accepted based on the 0.1 abalone/m^2 criteria (see "Decision Rules" this section). The method described in this section is identical to Lessard et al. (2002) with two exceptions: (1) the **higher** confidence interval is used for the density calculation, and (2) the population size is not calculated as it is unnecessary to evaluate the site. The 0.1 abalone/m^2 threshold was originally based on the measurable short-term goal of the National Recovery Strategy (see "Background" section). Although, this threshold in the recovery strategy is for the size category ≥100 mm SL, the higher confidence interval of the mean is used here.

Transect survey(s) outside the area of influence is also necessary to assess possible control site(s). The transect survey at the control site(s) may be done after the transect survey at the proposed site is completed and the site is given approval to go ahead. However, to minimize seasonality effects, transect survey(s) at possible control sites should be conducted within a month, two at the most. For information on where the control site should be, see Section 7. Control Site.

Transect placement

Transect positions are marked on nautical charts before the survey begins. The positions are selected randomly using the 'abalone habitat width' defined as the linear distance between the two furthest points of the abalone habitat. Transects are perpendicular to the shoreline at these positions. If the abalone habitat is discontinuous, separated by large areas of unsuitable abalone habitat (e.g., area of sand), the process to select the transect positions is repeated for each area of abalone habitat. At least ten transects should be surveyed in each abalone habitat area. If the width of the abalone habitat is shorter than 300m, a lesser amount of transects may be considered.

Transect layout

The primary sampling unit is a transect, made up of a variable number of secondary units: quadrats. Each transect is one meter wide and variable in length, depending on the slope of the substrate. Prior to entering the water, a lead line, the transect, is laid perpendicular to the shore, from the boat. If this is not possible, because of thick kelp beds or other environmental factors, then the divers should sample along a compass bearing perpendicular to the shore. The compass bearing must be strictly followed to avoid possible bias in the density estimate(s). Transects begin at 10 m chart datum and extend all the way into the shore, or to the point where the surge makes it impossible for the divers to work effectively.

Underwater survey (Filling out the "Abalone Field Sheet - Transect" Appendix B)

The secondary sampling unit consists of a 1 m x 1 m square quadrat that is placed beside the transect, 1 m away to avoid the area potentially disturbed by the lead line placement. Divers flip the quadrat parallel to the transect line, from deep to shallow. One diver records the data while the other measure the abalone and flips the quadrat. In each quadrat, the recording diver writes down 1) the shell length (SL in mm) of each abalone, 2) the depth, 3) the time, 4) the substrate type, 5) the number of urchins, 6) the number and relative size of abalone predators (sunflower starfish, Dungeness and red rock crabs, octopus, etc.) and 7) the % cover and dominant species of algae. The % cover of all algae combined is recorded by category: 1) canopy (kelp taller than 2m), 2) understorey (algae between 15cm and 2m in height), 3) turf (erect algae less that 15cm in height) and 4) encrusting (carpet-like algae). The dominant algal species (1-2) are recorded for the first 3 categories only. Appendix D lists the substrate and algae species codes to be used. The measuring diver must exercise caution when measuring abalone to ensure that the longest shell length is measured and the abalone is returned right side up on the rocks outside and behind of the quadrat. In order to minimize habitat damage, algae are not to be removed. Boulders are not to be moved to search for cryptic abalone. Caution must be exercised to ensure that abalone in upcoming quadrats are not disturbed.

Where the transect length is greater than 20 m, only every second quadrat needs to be sampled completely. If transects are longer than 60 m, abalone and depth can be sampled every second quadrat, and substrate and algae cover can be sampled every fourth quadrat. The frequency of sampling must be written on the underwater sheet.

Analytical methods

Calculations are included here for information only. The analysis will be performed by DFO Stock Assessment.

For each site, the estimated mean density, $\bar{d}_s$ (number/m^2), of abalone is calculated as:

$$\bar{d}_s = \frac{\sum_t ((c_t / q_t) * L_t)}{\sum_t L_t} \qquad (1)$$

The standard error of the mean density, se_s, is calculated as:

$$se_s = \sqrt{1 - \frac{n}{T}} * \sqrt{\frac{\sum_t ((c_t / q_t) * L_t - d_s * L_t)^2}{n * (n-1) * \bar{L}^2}} \qquad (2)$$

where n is the number of transects,
c_t is the number of abalone counted in transect t,
q_t is the number of quadrats sampled in transect t,
L_t is the length of transect t,
$\bar{L}$ is the mean transect length,
T is the total possible number of transects that can be sampled in the surveyed area and is equal to the 'abalone habitat width'.

This method accounts for the variable length of transects and for the variable proportion of quadrats surveyed along each transect.

To estimate the mean density (Equation 1) and standard error (Equation 2) for a specific size group (i) (*i.e.* ≥100 mm SL), the value c_t is substituted with c_{ti}, the counts of size group i in transect t.

At each site, the higher 90% confidence intervals of the mean density (*H90CI*), for all sizes or for a particular size group (≥100 mm SL) of abalone, are calculated using bootstrapping (Davidson and Hinkley 1997).

Data Management

All the data must be entered using the "Transect Data Entry" form in the Access database provided by DFO Stock Assessment. The fields that need to be filled on the field sheets and in the database are described in Appendix E. The original field data sheets as well as the electronic version in Access must be sent the Shellfish Data Unit, PBS, Nanaimo.

At PBS, a S-Plus script exists to analyze the data using the data directly from the database.

Decision rule for next phase

If the H90CI for all sizes is ≥0.1 abalone/m^2, the site is automatically rejected. If the H90CI for all sizes is <0.1 abalone/m^2, the responsibility of the decision to go ahead with permitting rests with the Habitat Management Program. If the site is accepted and an authorization is issued in accordance with section 35 of the *Fisheries Act*, the next phase is initiated.

7. Control site

Proposed control site(s) should be outside of the area of influence and within 1000m of the impacted sites to minimize differences in current and temperature regimes. For aquaculture proposals, the area of influence is determined by DEPOMOD. The control site must be within abalone habitat as described in Section 5. In general, the control site should have the same relative exposure, current regime and habitat characteristics. For example, it would be unsuitable to have smooth bedrock substrate within the abalone portion of the impacted site and boulders at the control site. It may also be unsuitable to have the control 'around the corner' where exposure to wave action would be different.

8. Phase 3: Monitoring program – Plot survey

The objective of this phase is to survey abalone within a small geographic area in order to calculate reliable density estimates with minimal variation. A density estimate with high precision is essential to detect impacts on abalone abundance as abalone density estimates have inherently high variance due to their aggregating behaviour. It is not rare to have standard deviations equal to or larger than the mean density estimates. For example, if the mean density estimate from the transect survey is 0.05 abalone/m^2 with a pooled standard deviation of 0.025 abalone/m^2, 34 samples would be necessary to detect a change in abundance of at least 50% with 95% confidence 80% of the time (17 impacted sites and 17 control sites). To increase precision, more plots can be placed in both the impacted and control sites; this would add a strata (high/low density areas) to the sampling design. In addition, more random transects can be added within each depth strata. The number of samples (transects) and strata can be determined using the transect survey results.

The plot survey is based on a stratified random sampling design. The current plot survey design is based on past survey results and builds on the Parks Canada and Haida Fisheries Program survey designs. Figure 1 gives a schematic diagram of the plot survey design. A better design would involve using the quadrats as the primary sampling unit and have each quadrat randomly placed within the plot. Strata (e.g. deep/shallow and/or high/low density areas) could also be used. However, the underwater logistics of such a design are impractical. The sampling design described below is for the minimum number of strata and samples required: one plot at each of the impacted and control sites with 2 depth strata in each plot and 10 or 8 transects for the shallow or deep reference lines, respectively.

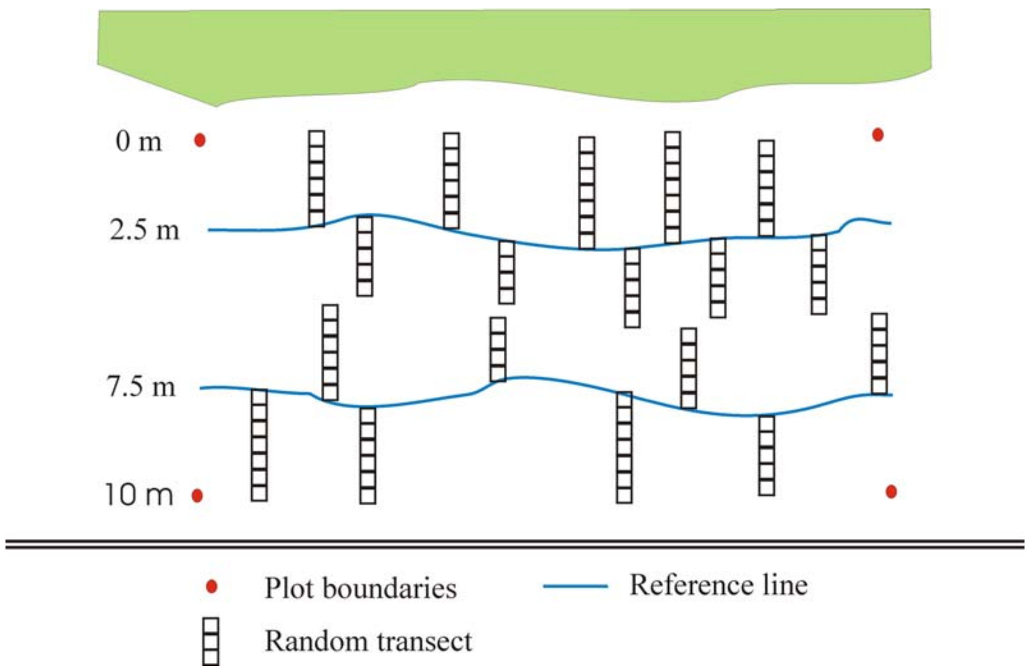


Figure 1. Schematic view of the plot survey design. Numbers on the left side are depths in metres (datum).

Reference line placement (in consultation with DFO Stock Assessment)

Two reference lines, 40m long each, are placed at 2.5m and at 7.5m below chart datum. The location of the reference lines are the middle of the 2 depth zones (0-5m and 6-10m) that are going to be sampled (the 2 strata in a stratified random sampling design). On each of the reference lines, several short perpendicular 1 m wide transects are surveyed, alternating on either side of the reference lines to minimize disturbance. The start location of each transect is chosen randomly prior to the start of the survey.

Choose 10 starting positions (out of 40 m) along the shallow reference line (2.5m) and 8 along the deep reference line (7.5m). Additionally, randomly choose the side of the transect where the first transect is placed and alternate thereafter (marked as "Start Down" or Start Up" on the field sheet).

Underwater survey (Filling out the "Abalone Field Sheet - Plot" Appendix C)

Each transect starts off the reference line at the randomly chosen location and the quadrat is flipped perpendicular to the reference line until the top, or bottom, of the depth zone is reached. No lead line is laid out for the random transects (a compass bearing can be taken, but this is not necessary as the transects are usually short, 4-8 quadrats long). One diver records the data while the other measures the abalone and flips the quadrat. In each quadrat, the recording diver writes down 1) the shell length (SL in mm) of each abalone, 2) the depth, 3) the time, 4) the substrate type, 5) the number of urchins, 6) the number and relative size of abalone predators (sunflower starfish, Dungeness and red rock crabs, octopus, etc.) and 7) the % cover and dominant species of algae. The % cover of all algae combined is recorded by category: 1) canopy (kelp taller than 2m), 2) understorey (algae between 5cm and 2m in height), 3) turf (erect algae less that 5cm in height) and 4) encrusting (carpet-like algae). The dominant algal species (1-2) are recorded for the first 3 categories only. The measuring diver must exercise caution when measuring abalone to ensure that the longest shell length is measured and the abalone is returned right side up on the rocks outside and behind of the quadrat. In order to minimize habitat damage, algae are not to be removed. Boulders are not to be moved to search for cryptic abalone. Caution must be exercised to ensure that abalone in upcoming quadrats are not disturbed. All quadrats are sampled completely. Once the transect is completed, the divers move to the random location and repeat the procedure until all locations have been completed within the depth strata.

Analytical methods

To calculate the mean and standard error within each strata *a*, the analysis is identical to the Transect Survey in Section 6.

For each site, the estimated mean density, d_s (number/^{2}), of abalone is calculated as:

$$d_s = (1/N)\sum n_a d_a \quad (3)$$

The standard error of the site mean density, se_s, is calculated as:

$$se_s = (1/N)\sum n_a se_a \quad (4)$$

where N is the total number of transects in all strata

n_a is the number of transects in strata *a*

d_a is the estimated mean density in strata *a*

se_a is the estimated standard error of the mean in strata *a*

The data will probably not be normally distributed and a nonparametric test such as the Wilcoxon paired-sample test should be used to look at differences between control and impacted sites.

Data Management

All the data must be entered using the “Plot Data Entry” form in the Access database provided by DFO Stock Assessment. The fields that need to be filled on the field sheets and in the database are described in Appendix E. The original field data sheets as well as the electronic version in Access must be sent to the Shellfish Data Unit, PBS, Nanaimo.

Decision rule for next phase

Once the monitoring is initiated at more than one site, the next phase should be instigated after 2-5 years depending on the extent of the changes. For example, if densities decrease at all impacted sites, but not at the control sites, by >50% within 2 years, then Phase 4 should be initiated.

9. Phase 4: Feed back

In phase 4 all monitoring data for a given type of work or development are pooled to determine overall impacts of this given type of work or development on abalone populations. Due to natural variation in abalone density and the low initial densities at approved sites

(<0.1abalone/m^2), a small change in abundance or distribution will be difficult to detect. Detecting changes less than 50% is therefore impractical because of the high variance and a much larger number of samples would be required.

Because of the possible implications of such an analysis, the results should be presented at PSARC.

10. References

Davidson, A.C., and Hinkley, D.V.. 1997. Bootstrap Methods and their Application. Cambridge University Press, Cambridge. 578 p.

Lessard, J, Campbell, A, and Hajas, W. 2002. Survey protocol for the removal of allowable numbers of northern abalone, *Haliotis kamtschatkana*, for use as broodstock in aquaculture in British Columbia. DFO Can. Sci. Advis. Sci. 2002/126: 41 p.

Sloan, N.A., and Breen, P.A.. 1988. Northern abalone, *Haliotis kamtschatkana*, in British Columbia: fisheries and synopsis of life history information. Can. Spec. Public. Fish. Aquat. Sci. 103: 46 p.

Appendix A. Third party biologist requirements

The minimum requirements for biological expertise for an independent third party biologist to conduct abalone surveys are:

- an established independent third party biological consultant company with experience working with DFO in accomplishing biological research including surveys; or
- an independent third party biologist accredited with a university or college degree in a related biological science that has preferably formed an independent company under their own name and has experience working with DFO in accomplishing biological research including surveys.

And

- meets a reference check for experience, competency, and demonstrated independent ‘arms length’ work experience;

And

- has passed a training session with DFO-Stock Assessment Division on conducting abalone surveys, including data collection and reporting. Training will be given by DFO-Stock Assessment Division and may be expected to include dive surveying.

And

- SCUBA dive certification, meeting WCB requirements

And

- bonded (to ensure confidentiality)

And

- knowledge of common algae, invertebrates and fish species.

And

- has access to Microsoft Access database software

Appendix B. Field data sheet for the transect survey

See Appendix E for field descriptions.

Abalone Field Sheet - Transect Page ____ of _____

Site Name:______________File number:_______________Date:___________
Measurer: _______________Recorder: _________________Time in:________Out:______
LAT:____________________LONG:____________________Direction (bearing in °):______
Transect number:_________ Quadrat Frequency:_______

Quad #	Depth ft.	Time	Substrate	Abalone Shell Length (mm)	Urchin Count	Predators	Canopy	Understory	Turf	En %

Substrate codes: 1 bedrock smooth, 2 bedrock crevices, 3 boulders, 4 cobble, 5 gravel, 6 pea gravel, 7 sand, 8 shell, 9 mud

General Algae codes:
EN encrusting (flat)
AC articulated coralline
KK kelp
B other brown
R red algae
G green algae

F foliose (leaf-like)
B branched (tree-like)
H filamentous (hair-like)

Grasses (GR)
PH *Phyllospadix*

Specific algae codes:
AG *Agarum*
AL *Alaria*
CO *Costaria*
CY *Cymathere*
DE *Desmarestia*
EG *Egregia*
IR *Iridea*
LA *Laminaria*
MA *Macrosystis*
NT *Nereocystis*
PL *Pleurophycus*
PO *Porphyra*
PT *Pterygophora*
SA *Sargassum*
UL *Ulva*

Appendix C. Field data sheet for the plot survey

note: Numbers/text in **bold** in the heading section of the field sheet are chosen randomly for each reference line for each period surveyed.

See Appendix E for field descriptions.

Abalone Field Sheet - Plot

Page ____ of _____

Site Name:______________ File number:_______________ Date:_____________________
Measurer: _______________ Recorder:__________________ Time in:_________ Out:_______
LAT:____________________ LONG:____________________ Direction (bearing in °):______
Reference Line:_________ (shallow or deep) Plot number:___________
Transect start locations: **2, 6, 13, 19, 21, 25, 31, 32, 34, 38** Start **Down**
Tide height (height@time):____

Quad #	Depth ft.	Time	Substrate	Abalone Shell Length (mm)	Urchin Count	Predators	Canopy	Understory	Turf	En %

Substrate codes: 1 bedrock smooth; 2 bedrock crevices; 3 boulders; 4 cobble; 5 gravel; 6 pea gravel; 7 sand; 8 shell; 9 mud

General Algae codes:
EN encrusting (flat)
AC articulated coralline
KK kelp
B other brown
R red algae
G green algae

F foliose (leaf-like)
B branched (tree-like)
H filamentous (hair-like)

Grasses (GR)
PH *Phyllospadix*

Specific algae codes:
AG *Agarum*
AL *Alaria*
CO *Costaria*
CY *Cymathere*
DE *Desmarestia*
EG *Egregia*
IR *Iridea*
LA *Laminaria*
MA *Macrosystis*
NT *Nereocystis*
PL *Pleurophycus*
PO *Porphyra*
PT *Pterygophora*
SA *Sargassum*
UL *Ulva*

Appendix D. Dive Codes

Table D1. Substrate codes

Code	Substrate
1	Bedrock - smooth
2	Bedrock - crevices
3	Boulders (rock bigger than a basketball)
4	Cobble (basketball down to 3 inches)
5	Gravel (3 inches down to 3/4 inch)
6	Pea gravel (3/4 inch down to 1/8 inch)
7	Sand
8	Shell
9	Mud

Table D2. Algae Codes

Code	Species
AA	Alaria nana
AB	Agarum cribosum
AC	Articulated corallines
AF	Agarum fimbriatum
AG	Agarum sp
AL	Alaria sp
AM	Alaria marginata
BB	brown branched
BF	brown foliose
BH	brown filamentous
CA	Callophyllis sp
CF	Codium fragile
CN	Constantinea sp.
CO	Costaria costata
CR	Cryptopleura sp
CS	Codium setchellii
CY	Cymathere triplicata
DB	Dictyota binghamiae
DE	Desmarestia sp
DF	Desmarestia foliacea
DL	Desmarestia ligulata
DU	Desmarestia munda
DR	drift algae
DS	Delesseria sp.
DV	Desmarestia viridis
EG	Egregia menziesii

Code	Species
EI	Eisenia arborea
EN	encrusting algae
ET	Enteromorpha sp
FU	Fucus gardneri
GA	Green Algae
GB	green branched
GE	Gelidium sp
GF	green foliose
GG	eelgrass & surfgrass
GH	green filamentous
GI	Gigartina sp
GR	Gracilaria pacifica
GS	Gastroclonium subarticulatum
HA	Halosaccion glandiforme
HE	Hedophyllum sessile
IR	Iridea sp
KK	Kelp
LA	Laminaria sp
LB	Laminaria bongardiana
LE	Leathesia difformis
LO	Lessoniopsis littoralis
LR	Laurentia spectabilis
LS	Laminaria saccharina
LT	Laminaria setchellii
MA	Macrocystis integrifolia

Code	Species
MI	Microcladia sp
NO	No Algae Present
NT	Nereocystis luetkeana
OD	Odonthalia sp
PH	Phyllospadix sp
PL	Pleurophycus gardneri
PO	Porphyra sp
PR	Prionitis sp
PT	Pterygophora californica
PV	Pelvetiopsis sp.
RB	red branched
RF	red foliose
RH	red filamentous
SA	Sargassum muticum
UL	Ulva sp, Monostroma sp or Ulvaria sp
UN	Unknown
ZO	Zostera sp

Appendix E. Database Field Descriptions

Field Name	Description
Site Name	The name of the proposed tenure as stated on the application
File Number	File number of the application *if available
Date	YYMMDD
Measurer	The name of the diver measuring and counting
Recorder	The name of the diver recording
Time In	The time (hh:mm) the diver leaves the surface *note: do not round to 5 mins.
Time Out	The time (hh:mm) the diver reaches the surface
LAT	Latitude of site in degrees and decimal minutes
LONG	Longitude of site in degrees and decimal minutes
Direction (bearing in º)	The bearing in which the transect is laid, in degrees
Reference Line	(shallow or deep)
Plot Number	Number assigned to the plot
Transect start locations	Randomly selected points along the transect to lay reference lines
Start	The direction from the main transect line to start the first quadrat, either shallow or deep
Tide height (height @time)	Several tide height to add to maximum depth to reach for strata (e.g., 4.5ft@10:30, 5ft@11:00, etc)
Quad#	The number of the quadrat being sampled
Depth (ft)	The gauge depth, in feet, for the quadrat being sampled
Time	The time (hh:mm) at which the diver was in that quadrat
Substrate	up to three codes for the most prominent substrate types in that quadrat (see sheet for codes)
Abalone Shell length (mm)	The measured shell length in mm of each abalone measured
Urchin Count	The number of urchins counted in that quadrat
Predators	(count/size/species) eg. 2MPy = 2 medium *Pycnopodia*
Canopy	% and species of the most dominant canopy species (kelp taller than 2m) (e.g., 50 MA = 50% *Macrocystis*)
Understory	% and species of the most dominant understorey species (algae between 5cm and 2m in height)
Turf	% and species of the most dominant turf species (erect algae less that 5cm in height)
En%	% (only) of cover of encrusting (carpet-like algae)

Appendix 3 Survey report of experiment to determine short-term impacts of finfish aquaculture on abalone

Survey report of an outplanting experiment using hatchery-reared abalone to determine short-term impacts of finfish aquaculture on abalone in the Broughton Group, July 2005 - March 2006

by

Sandie Hankewich

INTRODUCTION

Aquaculture, while an ancient practice in other parts of the world (Iwama 1991), is an emerging field in Canada. Canadian aquaculture production increased, on average, 19.8% per year between 1986 and 2001 (Lanteigne 2002), and is expected to continue to rise. The majority of production, 43% of the Canadian total in 2004, occurs in BC (Alain 2005). Finfish, especially salmon, account for 79% of the total production, and 89% of the total value of aquaculture in Canada (Alain 2005).

Recent studies have identified several possible detrimental effects of aquaculture to coastal ecosystems including, but not limited to: introduction of chemicals found in the feed and construction materials of the net pens (Winsby et al. 1996), eutrophication and/or possible oxygen deprivation spurred by excess food and feces in the water (Hargrave et al. 1993), release of pesticides and antibiotics used at fish farms (Haya et al. 2001), and burial by excess sedimentation (Ritz et al. 1989). However, the effect of fish farms on surrounding ecosystems is not yet fully understood (Milewski 2001). In particular, there is a serious lack of literature concerning aquaculture effects on hard-bottom substrates and moderate to high current speeds. Consequently, potential impacts on northern abalone (*Haliotis kamtschatkana)* populations and their habitat are unknown. As a result, the Department of Fisheries & Oceans Canada (DFO) initiated in a study to determine if finfish aquaculture has acute (*i.e.* immediate) impacts on abalone survival and growth in their natural environment. This nine month study assessed the growth and survival of small hatchery-produced abalone, which were placed within artificial habitats at existing aquaculture tenures as well as control sites in Queen Charlotte Strait (QCS).

METHODS

Experimental Sites

In order to test conditions as they exist in nature, this experiment was conducted *in situ*, rather than in a laboratory situation. The broodstock of the hatchery-produced abalone were originally from Cormorant Island, QCS. Due to possible disease transfer, outplanting occurred within the same biogeographic zone (Abalone Recovery Team 2002). Therefore only finfish aquaculture sites in the QCS were considered for this study. To simplify logistics, tenure sites which were operated by a single company were selected. Furthermore, the tenure sites had to be in operation throughout most of the experiment (July 2005 to March 2006). Given the above considerations, and exploratory SCUBA surveys examining habitat characteristics (substrate, algae cover and invertebrate community), tenure sites located at Swanson and Bonwick Islands (Figure 1) were selected. Control sites selected had similar habitat characteristics to the chosen tenure sites, and were located close to the tenure sites, but outside their area of influence, to ensure similar oceanographic conditions. Two substations were selected at each control and tenure site based on appropriate substrate availability: 6-8 m depth (chart datum), hard substrate with minimum slope surrounded by appropriate abalone habitat. Despite the fact that the sites constituted suitable habitat for abalone, no abalone were seen at the sites or the immediate surrounding areas during the preliminary dives.

Condo Description and Deployment

Juvenile abalone tend to hide inside crevasses or under large boulders, making these cryptic abalone very difficult for divers to find (Sloan and Breen 1988; J. Lessard, DFO, Nanaimo, pers. comm.). Artificial habitats (further referred to as condos), provide hiding spaces for juvenile abalone as well as standardized sample areas to monitor juvenile recruitment and growth (Davis 1995). Condos also reduce the intensity and effort (in dive time and sample sorting) associated with other methods such as underwater magnifying glass (Shepherd and Turner 1985, McShane and Smith 1988), rock removal combined with anesthesia (Prince and Ford 1985, Sasaki and Shepherd, 2001), and venturi suction sampler (McShane and Smith 1988). Condos are non-destructive to habitat (DeFreitas 2003; Jones et al. 2003). In this study condos also increased the probability of retaining juveniles at the experimental sites.

Each condo provided about 3.5m^2 of surface area and consisted of 24 concrete mini-blocks stacked within a modified commercial crab trap. Standard concrete blocks were cut into quarters longitudinally to produce 4 individual mini-blocks. Discarded commercial crab traps were altered by removing the central 'fishing' component, leaving a structurally effective frame of corrosion-resistant metal enclosed with stainless steel mesh. Diamond shaped openings in the wire mesh frames as well as the entry/exit hole allowed access to most abalone sizes and a hinged lid allowed divers access to load, remove and examine the concrete mini-blocks during deployment and sampling.

Condo deployment occurred on July 5-7, 2005. At each substation, three condos were placed 2-10 m apart, for a total of 24 condos in this study (Figure 1). Condos were deployed by lowering the traps and the cut-up blocks from a dive support vessel to the ocean floor. Divers then repositioned each structure with an industrial airlift bag. No anchoring mechanisms were needed to secure the condos in place as each condo weighed 120kg and possessed a stable base. The condos were located at an average depth of 4.7 m chart datum (Appendix A).

Abalone outplanting

Due to the threatened status of abalone, this study could not use wild abalone. Instead, 1200 hatchery-raised juvenile abalone, from the broodstock years of 1999 and 2000, were purchased from Malcolm Island Shellfish Cooperative (MISC). To prevent the spread of disease to the wild a juvenile subsample from MISC were examined for parasites and pathogens prior to onset of the experiment. Although the average size of the abalone was determined to be small for their age, no abnormalities, parasites, or pathology of infectious disease of concern were found (G. Meyer, DFO, Nanaimo, pers. comm.).

The juvenile abalone were outplanted directly into the condos on July 26-27, 2005, which allowed nearly a month for bacteria and diatoms to develop on the condos before abalone were transplanted into them. At the hatchery, abalone were measured and counted and placed in cages designed to hold abalone for transport and outplanting. Fifty abalone were placed in each cage. Every effort was made to ensure these abalone were in the best possible condition during transport, such as providing cold and well oxygenated water. Divers then transferred the abalone from each cage into a submerged condo, ensuring that all abalone attached to the concrete blocks before closing the lid of the crab trap.

Survey Methods

Subsequent to abalone outplanting in July, 2005, the condos were resurveyed on September 27-28, 2005, and again on March 21-22, 2006. A pair of divers sampled each condo by removing each concrete mini-block and examining it for abalone. All live abalone found were measured for maximum SL to the nearest millimeter using calipers. Abalone frequently develop drastically different shell colors when their environment or diet changes (Olsen 1968). This color change may be especially dramatic when abalone are moved from a hatchery (single food type) to the wild (varied food sources) (Gallardo et al. 2003). In our study, this distinct color band allowed the divers to visually determine and measure (for most of the abalone found) the amount each abalone had grown since outplanting. Empty abalone shells were measured and removed. After all blocks were examined, they were repositioned within the metal frame, and abalone were returned to the condo. Divers also recorded observations of urchins and common abalone predators such as *Pycnopodia helianthoides*, *Cancer productus*, and *Octopus dofleini*. Habitat data, such as percentage cover of the dominant algae, encrusting algae cover, and diatom presence was also recorded. Additionally, in the March survey only, divers recorded the relative abundance of other invertebrate or fish species (chitons, shrimp, hermit crabs, worms, barnacles, snails, and fish) using relative categories.

At the outplanting in July and the surveys in September and March, an underwater video camera was used to record short videos of each of the condos. The purpose of the video was to qualitatively determine the amount of silt at each site. Other quantitative methods exist, but they are time-consuming and often require on-site monitoring which was not possible for this study. The videos were later examined to confirm substrate types at each condo, as well as provide estimates of the silt accumulated on the condos, and information about other species present on the condos in the months of July and September. The video also provided general site information such as visibility and current speed at survey times, and the composition of algal communities surrounding the condos. Since data gathered from the video is primarily qualitative, results are presented as generalizations and, therefore, no statistical analysis was performed.

The water conditions at each site including: salinity (ppt), temperature (ºC), oxygen concentration (ppm), and oxygen percent saturation, were tested on September 27-28, 2005. An Oxyguard Handy Gamma was used to collect dissolved oxygen data, and a YSI 30 Salinity model 30/10ft collected data on salinity and temperature. Measurements at each substation were taken at the surface (1ft/0.30m depth), and at depth (30ft/9.14m).

Analytical methods

A Mann-Whitney U test was used to determine overall differences in density between the control and tenure sites. Since the results appeared to differ at the two islands, separate Mann-Whitney U tests were used to test for differences in density between control and tenure sites at Bonwick and Swanson Islands individually. Only September data were used in the density analyses, as the number of abalone recovered in March was too small for statistical comparison.

There appeared to be differences observed in the number of abalone found in condos that rested on bedrock vs. those on boulder. To test whether these differences were significant a 2 x 2 contingency table was constructed using bedrock and boulder as columns, and abalone groups of few and many as rows. A Fisher's exact test was then performed. In order to remove variation caused by site, the same procedure was repeated using only data from the control sites.

ANOVA was also used to compare the mean size of the abalone outplanted as well as abalone found in the September survey. Again, the March data was not tested alone due to small sample size. Differences in abalone growth between the control and tenure sites in September were compared using ANCOVA, with original size (calculated as the measured shell length – growth recorded) as the covariate. In all statistical analyses results were considered significant at the $\alpha = 0.05$ level.

RESULTS

Density

Of the 1200 abalone initially released in July, 2005, a total of 96 live abalone were found in September, 2005, and 12 in March, 2006 (Table 1). In September divers found 69 abalone at control sites: 55 at Bonwick Island, and 14 at Swanson Island. Twenty seven abalone were found at tenure sites: 14 and 13 at Bonwick and Swanson Islands, respectively. Fifty seven empty shells were recovered in September: 28 from control, and 29 from tenure sites. In March, 10 live abalone were found at control sites, all of which came from Bonwick Island. Two abalone were found at tenure sites, both at Swanson Island. Three shells were recovered at control sites, and 10 were found at tenure sites in March (Table 1).

Although there were more abalone found at the control than tenure sites in September, the difference was not significant (p=0.129). When considering sites separately, Bonwick Island had significantly more abalone at control sites than at tenure sites (p=0.035), while there was no difference in abundance at Swanson Island (p=1.00).

The number of abalone found did not appear to be distributed evenly throughout substrate types forming the bases of the condos. Condos were split into groups based on the predominant substrate type of their base: predominantly boulder (n=12), boulder and bedrock mixed (n=2), and predominantly bedrock base (n=10), (Table 2, Appendix A). Bonwick Island consisted of mainly bedrock based condos (8/12), while Swanson Island had mainly boulder based condos (9/12). The number of abalone/condo for each of the substrate groups was determined to be: 2.7 abalone/condo for boulder based condos, 2.5 abalone/condo for mixed, and bedrock based condos had a mean of 7.1 abalone/condo (Table 2). The overall differences between substrate types were nonsignificant (p=0.501), however there was a significant difference between substrate types at the control sites (p=0.045).

Size Frequency

At the time of outplanting (July, 2005), the mean shell length (SL) of all abalone was 23.92mm±0.09SE with a range of 11-35mmSL (Figure 2a). In September the mean SL was 26.68mm±0.40SE with a range of 17-37mm (Figure 2b). In March, the mean SL was 34.67mm±1.87SE with a range of 24-46mm (Figure 2c).

When results for Bonwick and Swanson Islands are combined, the mean SL for the control sites in July is 24.07mm±0.12SE with a range of 14-34mm, and the mean SL for tenure sites is 23.76mm±0.13SE with a range of 10-31mm (Figure 2a). In September, the mean SL for control sites was 27.35mm±0.49SE with a range of 18-38mm, (Figure 2b). The abalone within the tenure sites in September had a mean SL of 24.96mm±0.60SE and a range of 21-33mm (Figure 2b). In March, the abalone at the control sites had a mean SL of 35.60mm±1.93SE and a range of 30-47mm (Figure 2c). Only two abalone were found at the tenure sites with a mean SL of 30.00mm±6.00SE and values of 25mm and 37mm (Figure 2c).

There was no significant difference between abalone released in July at the control and tenure sites ($p=0.079$). In September, the abalone in tenure sites were significantly smaller than those in control sites ($p=0.007$). The March data were not tested alone as the data set was too small.

The mean growth of abalone at Bonwick Island control sites one and two was 5.45mm and 2.67mm, respectively, in September, and 16.80mm by March (Table 3). At Swanson Island in September the mean growth at control sites one and two was 4.67mm and 5.78mm, respectively. The abalone at tenure sites at Bonwick Island in September grew an average of 4.86mm at T1, and 1.50mm at T2. Swanson Island tenure sites had mean abalone growth rates of 1.50mm at T1 and 2.00mm at T2 in September. By March, only two abalone were found, both at Swanson Island; the abalone at T1 had grown 16.00mm and the abalone at T2 had not grown at all. Highly significant results were obtained on the growth data, with abalone located at tenure sites showing far less growth than abalone located at control sites ($p<0.001$).

Other species and Habitat data

Colonization of the condos between the time of deployment, and the first survey in July was low, consisting primarily of snails and hermit crabs which were more common at tenure sites than control sites (Appendix B). Urchins, especially green sea urchins (*Strongylocentrotus droebachiensis*), were common in the condos during both the September and the March surveys, and had similar abundances between the control and tenure sites. In September, nearly all of the condos had other species present. In general, Bonwick Island condos had more tenants than their Swanson Island counterparts, especially when considering urchins and barnacles. No clear pattern is present between control and tenure sites in September, except that chitons were seen only in the control sites. By March, all of the condos were being utilized by at least one other species. Predators consisted entirely of sunflower stars, *Pycnopodia helianthoides*, with the exception of a single red rock crab, *Cancer productus*, and showed the same general pattern of increasing numbers from July to March. Predators were also more prevalent at the control than tenure sites in March. Snails, mostly of the Genus *Nucella,* were common in the condos throughout the study, and were always more abundant at control sites than tenure. While *Nucella* are predatory, and it is possible that some abalone were preyed upon, none of the empty shells recovered show evidence (bore-holes) of this occurring.

Algae and encrusting algae were absent in July, and prevalent in September, especially at Bonwick Island (Appendix B). However, by March, few condos had algae left, and encrusting algae was absent again. Diatoms did not develop at any of the Bonwick Island control condos, though a few of the Swanson Island control condos showed diatom growth in July. At the tenure sites most of the condos had thick diatom growth in July and September, particularly at Swanson Island, though most condos were diatom-free in March.

The silt on the condos showed a general pattern of increasing from July to September, then decreasing in March at all sites (Appendix B). There was more silt at the tenure sites than control sites at all survey times, with the exception of one site at Bonwick Island in March. However there was considerably more silt on the condos at Swanson Island than those at Bonwick Island.

Water Conditions

Table 4 provides a summary of the water conditions on September 26-27, 2005 at all sites surveyed. All parameters measured were similar between locations, Swanson and Bonwick, as well as between tenure and control sites. Since only one measurement was taken at each site, statistical comparison was not possible. All sites had full strength sea water (no freshwater input) and saturation was relatively high.

DISCUSSION

The objective of this study was to determine if any of the altered environmental conditions which may be present at aquaculture sites have acute effects on juvenile abalone growth and survival. It was not possible, given the short duration of the experiment and budget constraints, to test for chronic impacts or in-depth physical/ chemical examination of the water and sediments.

Unfortunately, very few abalone were found in the September and March surveys, (only 8% and 1%, respectively, of the juveniles outplanted in July). These recovery rates are considerably lower than might be expected: in a California based study, Davis (1995) reports one year survival rates of 32% for juvenile *Haliotis rufescens* when transplanted from a hatchery to artificial habitats similar to the condos used in this study. Previous condo studies conducted by DFO, the Kitasoo, and the Haida, as well as the presence of other species in the condos in this study indicate that condos are indeed suitable habitat. Thus, there are two main reasons for the low recovery rates: the abalone have moved out of the condos or they have died. A combination of both these events is likely responsible for our observations.

Through tag recovery studies, adult abalone have been found to migrate as much as 48m over a period of a year (J. Lessard, DFO, Nanaimo, pers. comm.). Juvenile abalone in this study only needed to travel a few centimeters to exit the condos. In fact, the quality of the habitat surrounding the condos at control sites may have determined the amount of migration to a large extent, as considerably more abalone were found in condos with a bedrock base than in condos with a base of boulders, which had more available hiding spaces.

It is also likely that there was high mortality of the outplanted juveniles. The empty shells recovered account for only 6% of the original population; however, mortality cannot be estimated based on the shells recovered alone (Shepherd 1998). Many of the empty shells could have been swept away by current or wave action. Furthermore, the diver's ability to recover shell was dependant on the type of substrate present. The winter of 2005/2006 in coastal BC was characterized by severe storms (Environment Canada). These storms destroyed much of the local algae (seen quite clearly in the video data), including *Macrocystis integrifolia* and *Agarum* sp., which usually persist through the winter (Druehl and wheeler 1986; J. Lessard, DFO, Nanaimo, pers. comm.). The juvenile abalone had likely switched from feeding on diatoms to feeding on kelp (Sloan and Breen 1988; Breen and Adkins 1980), especially in control sites where diatoms were rare. Thus, winter die-off of the abalone was possibly exacerbated by loss of perennial kelp in the storms, resulting in a significant decrease in abalone found between September and March.

Preexisting health conditions of the study animals also probably contributed to the high mortality rates in this experiment. Following the conclusion of the experiment, several juvenile abalone from MISC were sent for examination due to unexplained mortality in the hatchery. The test results showed that the abalone were free of serious disease and parasites, however, they appeared to be seriously malnourished (S. Bower, DFO, Nanaimo; pers. comm.). Given this information, the abalone used in this study may have been unhealthy and/or starved at the time of outplanting. High mortality rates in the control group, as well as in the tenure group, support this conclusion. This should not, however, have significantly altered our findings in regards to the comparison between the control and tenure sites, as the original populations would have been equally afflicted. In retrospect, the compromised health of the abalone may have actually contributed to our comparison; nutrition is known to play a vital role in the stress tolerance of aquatic organisms (Martins 2006). In our study, malnourishment may have exaggerated the abalone's reaction to adverse conditions at the tenure sites, allowing us to observe effects more quickly than we would expect under normal conditions.

Sutherland et al. (2005), found increased macrofaunal abundance of some species under a farm at Kent Island, in the QCS. Our results did not show any indication that aquaculture is beneficial to abalone abundance. However, the Sutherland study was focused on less sensitive species than abalone and the fish farm at Kent Island had only been in operation for a short time (six months). Winsby et al. (1996) report that:

> …although initial inputs of organic matter often stimulate benthic production, continued inputs result in a reduced macrobenthic species richness and changes in community structure, as sensitive species die or migrate.

A recent study by Hall-Spencer et al. (2006) found that aquaculture can have effects on environments with hard-bottom substrates, even in areas with moderate currents. Visible waste was noted up to 100m from the cage edges, and abundances of scavenging fauna increased significantly, while sensitive species and overall biodiversity decreased with proximity to farms.

Yet, it is clear that some abalone are able to survive extended periods of time in the vicinity of aquaculture sites (Davies et al. 2006). Overall effects on mortality in this study were not significant, though this may largely be due to small sample sizes and high standard error. Furthermore, differences in density between control and tenure groups were far more pronounced at Bonwick Island, than at Swanson Island. The reason for this is unclear. Effects of organic waste from aquaculture sites are dependant on, water depth, farm size, bottom topography, and current velocity (Winsby et al. 1996). The mean depth of condos was slightly shallower at Swanson Island than Bonwick, and the net pen is larger at Swanson. All of which, theoretically, should lead to greater effects observed at Swanson Island. However, the current is much stronger at Swanson Island than Bonwick Island, which may be an important factor in decreasing the effects observed at Swanson Island. Substrate type may also be critical to understanding the differences between the two locations, based on the results at the control sites; Swanson Island has considerably more boulders surrounding the condos than Bonwick Island, which may have led to disproportional migration from the control condos at Swanson Island, minimizing the difference in numbers of abalone found at control and tenure sites. Nearly all of the difference in result at Bonwick and Swanson emerged from a single substation (BC1), where considerably more abalone were found than at all other sites. There were no observable physical differences between BC1 and BC2 (J. Lessard, DFO, Nanaimo, pers. comm.), or the sites at Swanson Island (aside from substrate). However, the circumstances in this study and the analysis do not allow us to determine whether the observed differences were due to an effect of substrate, or a product of some other anomaly present at BC1. Thus, we can only speculate. Though we cannot state the cause, the results at this single substation appear to be driving the observed differences in density of abalone.

In fact, the results of this study suggest that the effects of aquaculture on abalone growth may be more critical than effects on mortality: the growth shown by abalone at the tenure sites was much lower compared to those at the control sites. Over time, reduced growth may significantly influence abalone populations and recovery, as fecundity is strongly linked to body size (Campbell et al. 1992).

The water quality data gathered did not indicate any obvious differences between the control and tenure sites which would explain the suppressed growth rates at tenure sites. Furthermore, all values obtained were well within *H. kamtschatkana* tolerance limits for temperature (Dahlhoff and Somero 1993; Sloan and Breen 1988), and the salinity measured in this study is similar to average surface salinities for the QCS (Foreman et al. 2006). Likewise, the oxygen concentration measured in our study was much greater than possible late summer – early fall low concentrations (3-4ppm) in the QCS reported by Williams et al. (2003). However, only a single sample was taken at each depth strata per site, therefore, this data is not sufficient for comparison. Divers did observe some reduction (seen as black coloration on the bricks at the bottom of the condos) at some of the tenure sites, which suggests that differences in growth may be due to a parameter of water quality that was not measured.

CONCLUSION

Despite the short duration of the experiment, high mortality rates, and the resultant low sample sizes in the September and March surveys, the data strongly suggests slower growth rates in abalone located near aquaculture tenure sites than those in nearby control sites, though effects on mortality are inconclusive. Nevertheless, the topic of this study is one that merits further research, and the methods and results of this experiment may provide direction for future study.

REFERENCES

Abalone Recovery Team. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in Canada. 22 pp. http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/documents/AbaloneRecovStrategy_e.htm

Alain, B. 2005. Taking stock: a profile of Canada's aquaculture industry. VISTA on the agri-food industry and the farm community. 6 pp. http://www.statcan.ca/english/freepub/21-004-XIE/21-004-XIE2005005.pdf (Accessed August 29, 2006).

Breen, P.A., and Adkins, B.E. 1980. Spawning in a British Columbia population of northern abalone, *Haliotis kamtschatkana*. Veliger 23: 177-179.

Campbell, A., Manely, I., and Carolsfeld, W. 1992. Size at maturity and fecundity of the abalone, *Haliotis kamtschatkana* (Jonas), in northern British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2169: 47-65.

Dahlhoff, E., and Somero, G.N. 1993. Effects of temperature on mitochondria from abalone (Genus *Haliotis*): adaptive plasticity and its limits. J. exp. Biol. 185:151-168.

Davies, K., Atkins, M., and Lessard, J. 2006. Survey of northern abalone, *Haliotis kamtschatkana*, populations in Queen Charlotte and Johnstone Straits, British Columbia, May 2004. Can. Manuscr. Rep. Fish. Aquat. Sci. 2743: iii + 17 p.

Davis, G.E. 1995. Recruitment of juvenile abalone (*Haliotis* spp.) measured in artificial habitats. Marine and Freshwater Research 46: 549-554.

DeFreitas, B. 2003. Estimating juvenile northern abalone (*Haliotis kamtschatkana*) abundance using artificial habitats. J Shellfish Res. 22: 819-823.

Druehl, L.D., and Wheeler, W.N. 1986. Population biology of *Macrocystis integrifolia* from British Columbia, Canada. Marine Biology 90: 173-179.

Environment Canada. Climate Data and Information Archive. http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html. (Accessed October 30, 2006).

Foreman, M.G.G., Stucchi, D.J., Zhang, Y., and Baptista, A.M. 2006. Estuarine and Tidal Currents in the Broughton Archipelago. 17pp. http://www.ccalmr.ogi.edu/CORIE/modeling/elcirc/broughton.pdf. (Accessed September 12, 2006).

Gallardo, W.G., Bautista-Teruel, M.N., Fermin, A.C., and Marte, C.L. 2003. Shell marking by artificial feeding of the tropical abalone *Haliotis asinina* Linne juveniles for sea ranching and stock enhancement. Aquaculture Research 34: 839.

Hall-Spencer, J., White, N., Gillespie, E., Gillham, K., and Foggo, A. 2006. Impact of fish farms on maerl beds in strongly tidal areas. Mar. Ecol. Prog. Ser. 326: 1-9.
Hargrave, B.T., Duplisea, D.E., Pfeiffer, E., and Wildish, D.J. 1993. Seasonal changes in benthic fluxes of dissolved oxygen and ammonium associated with marine cultured Atlantic salmon. Mar. Ecol. Prog. Ser. 96: 249-257.
Haya, K., Burridge, L.E., and Chang, B.D. 2001. Environmental Impact of chemical wastes produced by the salmon aquaculture industry. J. Mar. Sci. 58: 492-496.
Iwama, G.K. 1991. Interactions between aquaculture and the environment. Critical Reviews in Environmental Control 21: 177-216.
Jones, R., DeFreitas, B., Sloan, N., Lee, L., von Boetticher, K., and Martin, K. 2003. Abalone stewardship in Haida Gwaii: Forging a long-term commitment. Proceedings of the workshop on rebuilding techniques for abalone in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 5-19.
Lanteigne, S. 2002. Current status and potential of the Canadian aquaculture industry. 70 pp. http://www.dfo-mpo.gc.ca/aquaculture/ref/Study1_e.pdf. (Accessed October 31, 2006)
Martins, T.G., Cavalli, R.O., Martino, R.C., Rezende, C.E.M., and Wasielesky, W. 2006. Larviculture output and stress tolerance of *Farfantepenaeus paulensis* postlarvae fed Artemia containing different fatty acids. Aquaculture 252: 525-533.
McShane, P.E., and Smith, M.G. 1988. Measuring abundance of juvenile abalone, *Haliotis rubra* Leach (Gastropoda: Haliotidae); comparison of a novel method with two other methods. Aust. J. Mar. Freswater Res. 39: 331-336.
Milewski, I. 2001. Impacts of salmon aquaculture on the coastal environment: A review. Marine Aquaculture: 166-197.
Olsen, D. 1968. Banding patterns of *Haliotis rufescens* as indicators of botanical and animal succession. Biol. Bull. 134: 139-147.
Prince, J.D., and Ford, W.B. 1985. Use of anaesthetic to standardize efficiency in sampling abalone populations (genus *Haliotis*: Mollusca: Gastropoda). Aust. J. Mar. Freshwater Res. 36: 701-706
Ritz, D.A., Lewis, M.E, .and Shen, M.A. 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages. Mar. Biol. 103:211-214.
Sasaki, R. and Shepherd, S.A. 2001. Ecology and post-settlement survival of the ezo abalone *Haliotis discus hannai*, on Miyagi coasts, Japan. J. Shellfish Res. 20: 619-626.
Shepherd, S.A. 1998. Studies on southern Australian abalone (genus *Haliotis*) XIX: long-term juvenile mortality dynamics. J. Shellfish Res. 17: 813-825.
Shepherd, S.A., and Turner, J.A. 1985. Studies on southern Australian abalone (genus *Haliotis*). VI. Habitat preferences, abundance, predators of juveniles. J. Exp. Mar. Biol. Ecol. 93: 285-298.
Sloan, N.A., and Breen, P.A. 1988. Northern abalone, *Haliotis kamtschatkana*, in British Columbia: fisheries and synopsis of life history information. Can. Spec. Public. Fish. Aquat. Sci. 103: 11p.
Sutherland, T.F., Levings, S.A., Peterson, S.A., Sinclair, D., Jepps, S., Gillard, B., Knight, J., McPhie, R., Walton, P., Lessard, J., McGreer, E., and Taekema, B.

2005. Data report on a benthic survey conducted near Kent Island, British Columbia. Can. Data Rep. Fish. Aquat. Sci. 1166: 1-27.

Williams, I.V., Groot, C., and Walthers, L. 2003. Possible factors contributing to the low productivity of the 2000 brood year pink salmon, *Oncorhynchus gorbuscha*, that migrate through the Broughton Archipelago. 46 pp. http://www.davidsuzuki.org/files/Oceans/PinkSalmon_full_report.pdf (Accessed October 19, 2006).

Winsby, M., Sander, B., Archibald, D., Daykin, M., Nix, P., Taylor, F.J.R., Munday, D. 1996. The environmental effects of salmon netcage aquaculture in British Columbia- A literature review. Report prepared for the Ministry of Environment, Lands, and Parks, Victoria, BC, by Hatfield Consultants Ltd. And EVS Environmental Consultants.

Table 1. Summary of density results of live abalone and empty shells at control and tenure sites on Bonwick and Swanson Islands, Queen Charlotte Strait during dive surveys on July, 2005, September, 2005, and March, 2006.

	Control		**Tenure**		**Total**	
Survey Date	No. Live Abalone	No. Empty Shells	No. Live Abalone	No. Empty Shells	No. Live Abalone	No. Empty Shells
Bonwick						
July	300	0	300	0	600	0
September	55	24	14	22	69	46
March	10	2	0	1	10	3
Swanson						
July	300	0	300	0	600	0
September	14	4	13	7	27	11
March	0	1	2	9	2	10
Combined						
July	600	0	600	0	1200	0
September	69	28	27	29	96	57
March	10	3	2	10	12	13

Table 2. Number of condos and total number of abalone/condo (September + March) grouped by the predominant substrate underneath the condos (boulder, bedrock, and a mixture of boulder and bedrock) by site at Bonwick and Swanson Islands, Queen Charlotte Strait.

	Bonwick Island			Swanson Island			Total		
Substrate type	No. condos	No. abs	Abs/ condo	No. condos	No. abs	Abs/ condo	No. condos	No. abs	Abs/ condo
Control									
Boulder	1	4	4.0	6	14	2.3	7	18.0	2.6
Mixed	1	4	4.0	0			1	4.0	4.0
Bedrock	4	57	14.3	0			4	14.3	3.6
Tenure									
Boulder	2	6	3.0	3	8	2.7	5	14	2.8
Mixed	0			1	1	1.0	1	1	1.0
Bedrock	4	8	2.0	2	6	3.0	6	14	2.3
Total									
Boulder	3	10	3.3	9	22	2.4	12	32	2.7
Mixed	1	4	4.0	1	1	1.0	2	5	2.5
Bedrock	8	65	8.1	2	6	3.0	10	71	7.1

Table 3. Number of abalone, mean shell length (SL), and mean growth in mm of abalone measured in control and tenure sites at Bonwick and Swanson Islands, Queen Charlotte Strait, in September, 2005, and March, 2006. Note: growth was not measured for all abalone, thus the numbers of abalone in this table may not match those in Table 1.

	Bonwick Island			Swanson Island		
Site	**No. of abalone**	**Mean SL (mm)**	**Mean Growth (mm)**	**No. of abalone**	**Mean SL (mm)**	**Mean Growth (mm)**
September						
Control 1	42	28.55	5.45	3	25.67	4.67
Control 2	9	25.56	2.67	9	26.44	5.78
Tenure 1	7	28.29	4.86	6	24.67	1.50
Tenure 2	6	23.17	1.50	2	22.00	2.00
March						
Control 1	10	35.60	16.80	0		
Control 2	0			0		
Tenure 1	0			1	36.00	16.00
Tenure 2	0			1	24.00	0.00

Table 4. Water quality data taken at each of the control and tenure sites at Bonwick and Swanson Islands, Queen Charlotte Strait, in September, 2005. Measurements were taken at the surface (1ft depth, =S) and at depth (30ft, =D). In the site names B=Bonwick Island, S=Swanson Island, C=control, F=tenure, followed by the site number. X denotes equipment malfunction when measurements could not be taken.

Date	**Site**	**Salinity ppt**		**Temp (ºC)**		**O_2 ppm**		**O_2 % Sat**	
		S	D	S	D	S	D	S	D
Control									
Sep-27	BC 1	31.7	31.7	10.3	10.7	6	6.3	72	79
Sep-27	BC 2	30.9	32	10.4	11.4		6.2	X	80
Sep-28	SC 1	31.8	X	9.4	X	6.7	6.5	79	76
Sep-28	SC 2	X	X	X	X	6.7	6.4	79	75
	Mean	31.5	31.9	10.0	11.1	6.5	6.4	76.7	77.5
Tenure									
Sep-27	BT 1	31.4	31.8	10.3	11.3	6.1	6.6	80	81
Sep-27	BT 2	31.3	32.4	10.7	10.2	7	6	87	72
Sep-28	ST 1	32.1	32.1	9.4	9.6	6.5	7	75	82
Sep-28	ST 2	31.6	32	9.4	9.8	6.3	6.5	73	76
	Mean	31.6	32.1	10.0	10.2	6.5	6.5	78.8	77.8

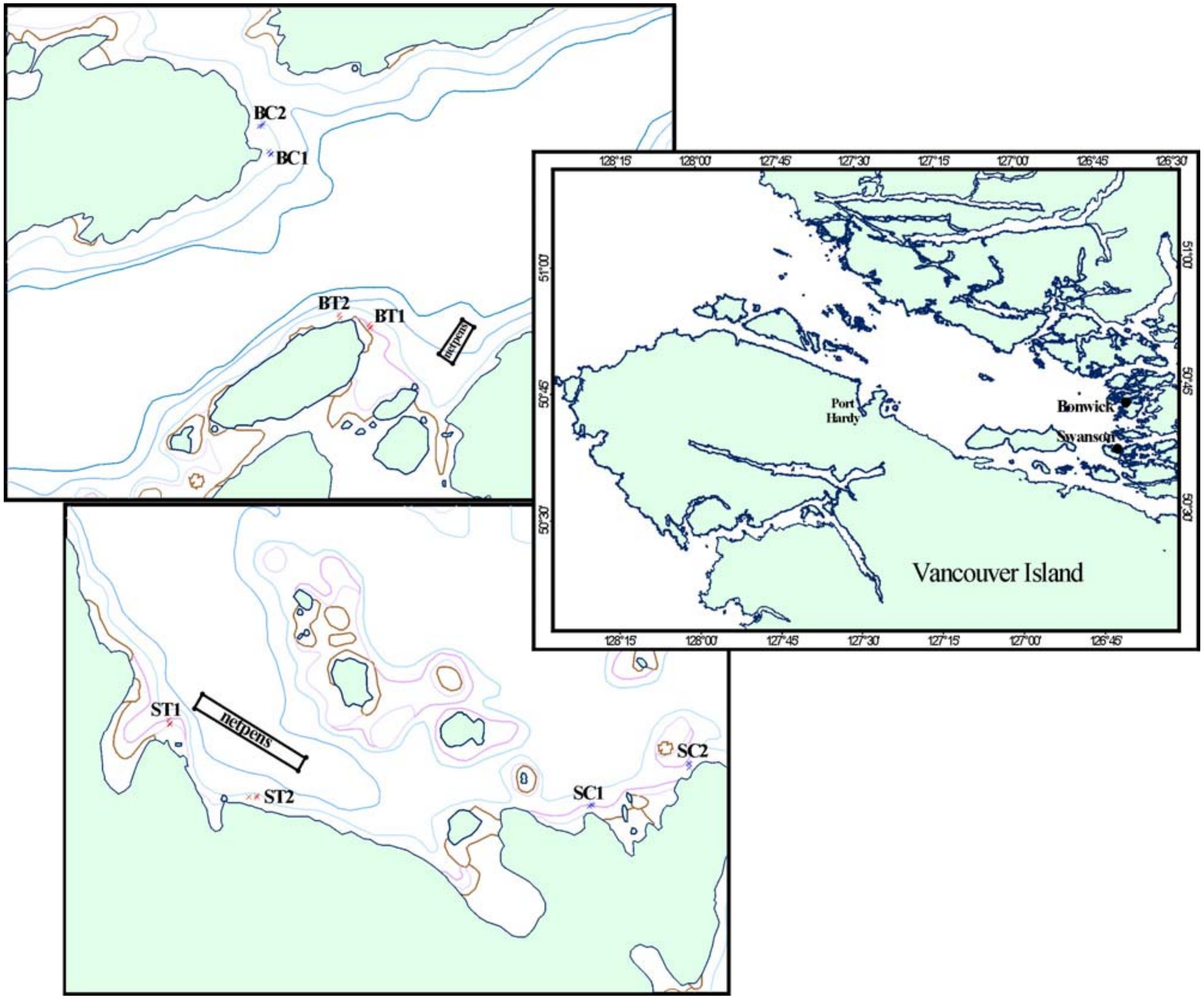


Figure 1. Maps of the Queen Charlotte Straight (right), and the sites at Bonwick (top) and Swanson (bottom) Islands showing condo placement. Site labels begin with the first letter of the location name, followed by T for tenure and C for control sites, and the substation number. Condos are marked with X.

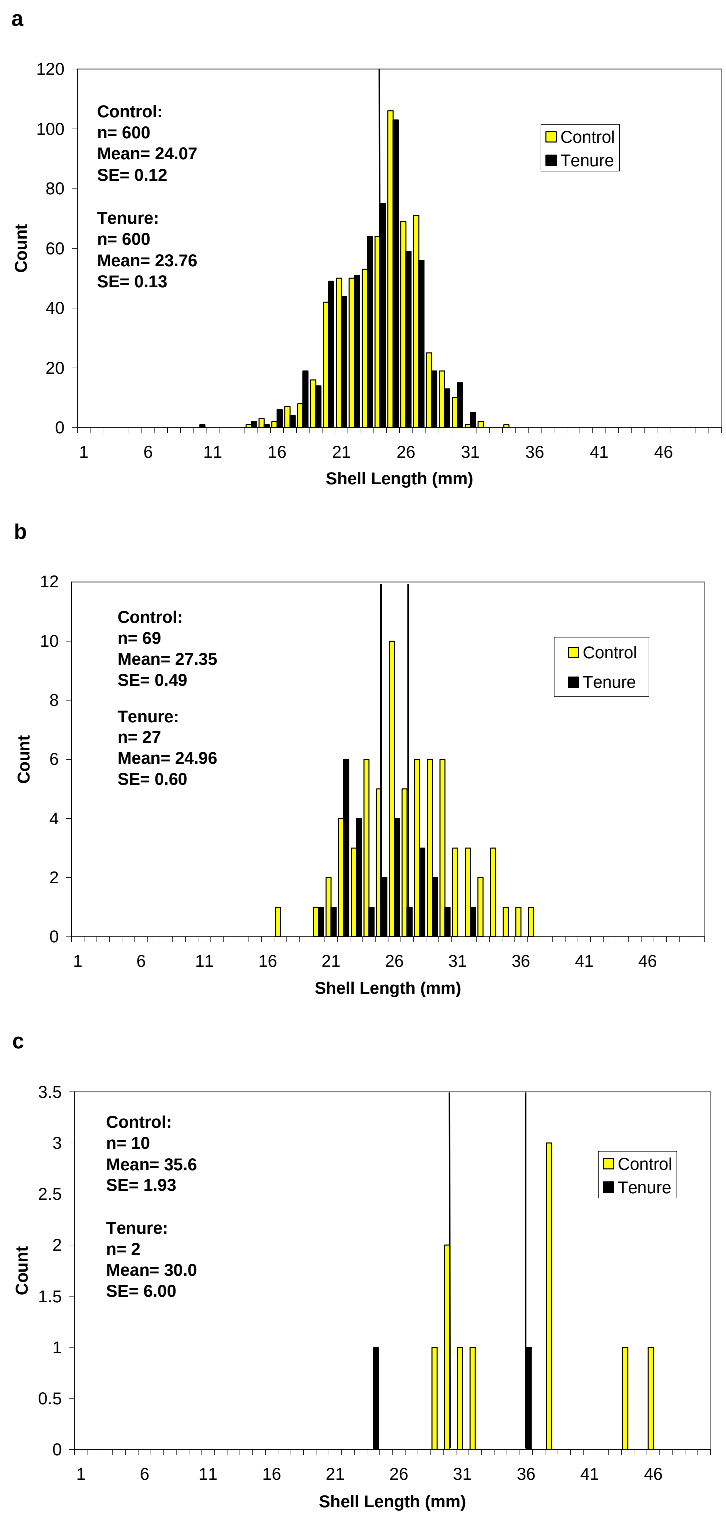


Figure 2. Size frequency distributions of abalone measured in the Queen Charlotte Straight in (a) July, 2005, (b), September, 2005, and (c), March, 2006. Results from both locations (Swanson and Bonwick Islands) are combined and split into control (light) and tenure (dark) sites. Vertical lines across represent mean shell lengths for tenure and control sites, respectively.

Appendix A. Depths and predominant substrate types for each condo at control and tenure sites in Bonwick and Swanson Islands in the Queen Charlotte Strait

The most common substrate types are listed (1 = dominant, 2 = second, and 3 = third) where substrate code 1 = smooth bedrock, 2 = bedrock with crevices, 3 = boulders, 4 = cobble, 7 = sand, 8 = shell.

	Bonwick Island					Swanson Island				
			Substrate					Substrate		
Site	Condo Number	Depth (m)	1	2	3	Condo Number	Depth (ft)	1	2	3
Control	C1-13	4.0	1	2		C1-19	6.4	4	3	8
Control	C1-14	4.6	1	2	8	C1-20	5.2	3	2	8
Control	C1-15	4.6	1	2	8	C1-21	5.2	3		
Control	C2-16	6.4	3	8		C2-22	4.6	3	4	8
Control	C2-17	4.9	1	2	3	C2-23	3.7	3	4	
Control	C2-18	6.4	1	2	8	C2-24	4.0	3	4	8
Tenure	T1-7	5.8	2	7	1	T1-1	5.2	1	2	
Tenure	T1-8	5.2	3	7	8	T1-2	4.3	1	2	3
Tenure	T1-9	4.3	7	8	1	T1-3	2.4	1	2	8
Tenure	T2-10	3.4	3			T2-4	2.4	3		
Tenure	T2-11	4.6	1	2	8	T2-5	4.9	3	8	
Tenure	T2-12	5.2	2	1	8	T2-6	4.3	3	8	

Appendix B. Summary of habitat data for each condo at Bonwick and Swanson islands, Queen Charlotte Strait, in July, 2005, September, 2005, and March, 2006

Condo numbers beginning with “C” indicate control sites, while “T” indicates tenure sites. The first digit of the condo number is the site number, and the number following the dash is the actual number of the condo. The other species observed on or in the condos where P= predators (PY= *Pycnopodia helianthodoides* ro RR= red rock crab, *Cancer productus* followed by a code for size as L= large, M= medium, and S= small;), U= urchins (all green sea urchin, *Strongylocentrotus droebachiensis*, except for a single purple sea urchin, *Strongylocentrotus purpuratus*, denoted with *), C= chitons, Sh= shrimp, W= tube worms, B= barnacles, Sn= snails, and F= fish. The relative abundance of other species are placed into categories where S= single, F= few, M= many, A= abundant, and VA= very abundant. The algae are listed as species code followed by the percentage cover on the condo, where AL= *Alaria* sp, AG= *Agarum* sp, BB= brown branched, NT= *Nereocystis luetkeana*, RB= red branched, and RF= red foliose. Encrusting algae (Enc) is listed as percentage cover. Diatoms (D) are listed as present (Y)/ absent (N). Silt accumulated on the condos has been given a number code from 0-4, where a higher number indicates more silt cover. Cells where and X occurs are times where the video camera failed, and no other data was available.

		Other Species												
Location	**Condo #**	**P**	**U**	**C**	**Sh**	**H**	**W**	**B**	**Sn**	**F**	**Algae**	**Enc (%)**	**D**	**Silt**
July														
Bonwick	C1-13					F			F		0	0	N	0
Bonwick	C1-14								F		0	0	N	0
Bonwick	C1-15								F		0	0	N	0
Bonwick	C2-16								M		0	0	N	1
Bonwick	C2-17								M		0	0	N	0
Bonwick	C2-18								M		0	0	N	1
Bonwick	T1-7								F		0	0	N	2
Bonwick	T1-8										0	0	Y	1
Bonwick	T1-9				F			F			0	0	N	1
Bonwick	T2-10					F			F		0	0	Y	1
Bonwick	T2-11					M					0	0	N	0
Bonwick	T2-12					M			F		0	0	Y	0
Swanson	C1-19				F						0	0	Y	2
Swanson	C1-20										0	0	N	3
Swanson	C1-21								F		0	0	N	2
Swanson	C2-22										0	0	N	3
Swanson	C2-23		1								0	0	Y	3
Swanson	C2-24										0	0	Y	3
Swanson	T1-1										0	0	Y	4
Swanson	T1-2	X	X	X	X	X	X	X	X	X	0	0	Y	4
Swanson	T1-3										0	0	Y	4
Swanson	T2-4					F					0	0	N	3
Swanson	T2-5				F	F					0	0	Y	4
Swanson	T2-6								F		0	0	N	3

Appendix B. Con't.

		Other Species												
Location	**Condo #**	**P**	**U**	**C**	**Sh**	**H**	**W**	**B**	**Sn**	**F**	**Algae**	**Enc (%)**	**D**	**Silt**
September														
Bonwick	C1-13	0	3		M	F	A		F		RB 5	10	N	1
Bonwick	C1-14	1 PYS	3	F	F	F		VA	F		RB 5	30	N	1
Bonwick	C1-15	0	0					VA	M		RB 10	20	N	1
Bonwick	C2-16	1 PYS	1*	X	X	X	X	X	X	X	RB 10	40	N	X
Bonwick	C2-17	0	1	F				F	M		RB 10	10	N	1
Bonwick	C2-18	0	3			F	F	F	M	S	RB 10	20	N	1
Bonwick	T1-7	0	4					M			RB 5	10	Y	2
Bonwick	T1-8	0	0		M			A	F		RB 10	5	Y	2
Bonwick	T1-9	I PYS	0		M			M	F		RB 10	5	Y	2
Bonwick	T2-10	0	0			M		VA	M		RB 10, BB 5	0	Y	2
Bonwick	T2-11	0	0			A		VA	M		RB 5, BB 5	0	Y	2
Bonwick	T2-12	0	3		F	M		VA	F		RB 5	0	Y	2
Swanson	C1-19	0	2	F	A	F			A		RB 5	20	N	1
Swanson	C1-20	0	1		M	F		F	M		RB 2	5	N	2
Swanson	C1-21	0	0					F	M		RB 10	20	N	1
Swanson	C2-22	0	1		F			F			0	0	N	2
Swanson	C2-23	0	0			F			F		AL, NT	0	N	3
Swanson	C2-24	0	0		F				F		0	0	N	3
Swanson	T1-1	0	2						M		0	20	Y	3
Swanson	T1-2	0	0		M	F		M	F		0	20	Y	3
Swanson	T1-3	0	0		M						0	0	Y	3
Swanson	T2-4	0	0						F		AG 5, RF 5	0	N	3
Swanson	T2-5	1 PY	0						F		0	0	N	2
Swanson	T2-6	0	0								0	0	N	3
March														
Bonwick	C1-13	0	2	F	A	A	A		A		0	0	N	2
Bonwick	C1-14	0	1	F	F	A	F	F	A		0	0	N	1
Bonwick	C1-15	2 PY	1	F	F	A	VA	F	A		0	0	N	0
Bonwick	C2-16	1 PY	0	M	VA	M	F		M		0	0	N	2
Bonwick	C2-17	0	0	F	A	M			M		0	0	N	2
Bonwick	C2-18	1 RR	0	F		F	F		A		RB 2	0	N	1
Bonwick	T1-7	1 PYS	0	F	VA	F	F	M	F	S	RB 10	0	Y	0
Bonwick	T1-8	3 PY	1		VA		A	F		S	0	0	N	1
Bonwick	T1-9	0	1		A		F	F			RB 10	0	Y	2
Bonwick	T2-10	0	0			M	A	VA	M	S	0	0	N	0
Bonwick	T2-11	0	0	F		F	F	VA	F		RF 5	0	N	0
Bonwick	T2-12	0	0		M	F		M	M		RB 2	0	N	1

Appendix B. Con't.

		Other Species												
Location	**Condo #**	**P**	**U**	**C**	**Sh**	**H**	**W**	**B**	**Sn**	**F**	**Algae**	**Enc (%)**	**D**	**Silt**
Swanson	C1-19	0	0	M	A	M	F	F	M		0	0	N	1
Swanson	C1-20	4 PY	2		F	F		F	M		0	0	N	1
Swanson	C1-21	1 PY	0	F	A		M		M		0	0	N	1
Swanson	C2-22	1 PY	0			F			M		0	0	N	2
Swanson	C2-23	1 PY	8		F	F	M		A		0	0	N	2
Swanson	C2-24	2 PY	0			F		F	F		0	0	N	2
Swanson	T1-1	0	9			M			M		0	0	N	3
Swanson	T1-2	0	0	F	A				F		0	0	N	2
Swanson	T1-3	0	1		M				F		0	0	N	X
Swanson	T2-4	0	0		F		F		F		RB 10	0	N	1
Swanson	T2-5	0	0		F	F	F				RB 2	0	N	4
Swanson	T2-6	0	0			F			F		0	0	N	4

Appendix 4 Request for Working Paper

PSARC INVERTEBRATE SUBCOMMITTEE

Date Submitted: **November, 2006**

Individual or group requesting advice:

- L. Convey (Resource Management Biologist – Abalone and Species at Risk), K. West (Species at Risk Recovery Planning Coordinator), and DFO Habitat Managers.

Proposed PSARC Presentation Date: November 2006

Subject of Paper (title if developed): Northern abalone 'allowable harm assessment'.

Science Lead Author: Joanne Lessard

Resource Management Lead Author: (Laurie Convey lead but not author)

Rationale for request:

- Northern abalone (*Haliotis kamtschatkana*) is listed and protected as threatened under Schedule 1 of the Species at Risk Act (SARA).
- SARA prohibits killing, harming, harassing, capturing, and taking northern abalone, and damaging or destroying abalone residences or its critical habitat (once critical habitat is identified in a recovery strategy or action plan).
- Activities affecting a listed species or its critical habitat may be permitted under SARA Section 73 or Section 83(4).
- A framework for an 'allowable harm assessment' is being adopted nationally to provide science advice for permitting activities under SARA that may affect a listed species or its critical habitat.
- Works or developments that are on, in or under the water may affect abalone and/or abalone habitat. DFO Habitat Managers require protocols for the authorization under *Fisheries Act* Section 35 of activities that may affect abalone habitat.
- Recovery activities for northern abalone are being implemented under the 'National Recovery Strategy for the Northern Abalone in Canada' (finalized under the Accord for the Protection of Species at Risk) and its draft action plan, and may affect northern abalone in the wild.

Objectives of Working Paper:

- To provide an 'allowable harm assessment' for northern abalone following the nationally developed framework (http://www.dfo-mpo.gc.ca/csas/Csas/Proceedings/2004/PRO2004_040_B.pdf).

Question(s) to be addressed in the Working Paper:

Follow the nationally developed framework.

1. What is present/recent species trajectory?
2. What is present/recent species status?
3. What is expected order of magnitude / target for recovery?
4. What is expected general time frame for recovery to the target?
5. What is the maximum human-induced mortality that the species can sustain and not jeopardize survival or recovery of the species?
6. What are the major potential sources of mortality/harm? More specifically for northern abalone, these may include:
   - Illegal harvest
   - Possible future directed fishing for food, social ceremonial harvest by First Nations
   - Predation by sea otters
   - Detrimental alteration of habitat by permitted activities (e.g. nearshore works or developments, finfish aquaculture farms)
   - Direct mortality of abalone by permitted habitat alterations
   - Abalone aquaculture
   - Population rebuilding under the recovery strategy
     - out-planting hatchery-raised northern abalone to the wild
     - aggregating mature (wild) reproductive adults
   - Research recommended under the recovery strategy
     - tagging
     - population surveys
7. Quantify to the extent possible the amount of mortality or harm caused for each activity.
8. Aggregate total mortality/harm attributable to all human causes and contrast with that determined in question 5.
9. Are there reasonable alternatives to the activity with the potential for less impact?
10. Are there feasible measures that could be taken to minimize impacts?
11. Is the expected level of harm below that determined in question 5? Does the projected population trajectory indicate the activity will jeopardize survival or recovery?
12. Prepare options (where justified) and recommendations for the permitting of activities, including rationales and relevant conditions.

Stakeholders Affected:

- Works or developments that may affect abalone or abalone habitat and aquaculture farms. (Will be diverse and difficult to specify).
- First Nations and stewardship groups involved in abalone rebuilding or research.
- Abalone researchers.
- First Nations.

How Advice May Impact the Development of a Fishing Plan:

- There is no fishing plan for northern abalone, all harvest is closed.

- The recovery strategy could be used to permit activities pursuant to SARA Section 83(4).

Timing issues related to when Advice is necessary:

- Works and development on, in and under water are ongoing and repairs may at times be urgent for human safety reasons. Applications for aquaculture leases and tenures are referred regularly to DFO from the Province of BC. DFO Habitat Managers urgently require protocols for the authorization of these activities under the *Fisheries Act* Section 35.
- Abalone rebuilding and research activities have been well underway since 1999. Previous PSARC papers are available to provide guidance to DFO in the issuance of permits for many of these activities, however, these have not yet been compiled under the nationally adopted framework for an 'allowable harm assessment'.