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Survey protocol for the removal of allowable numbers of northern abalone, *Haliotis kamtschatkana*, for use as broodstock in aquaculture in British Columbia

Protocole de relevé pour le prélèvement d'un nombre autorisé d'ormeaux nordiques (*Haliotis kamtschatkana*) aux fins d'établissement de stocks de géniteurs de culture en Colombie-Britannique

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Abstract

A survey protocol and methodology to determine abalone abundance has been in use for the last three years. The present paper reviews the data collected during 6 surveys for broodstock purposes and uses these data to determine the appropriate level of removal. The proposed survey protocol and broodstock removal considerations are discussed.

These surveys provide little evidence of recovery of abalone populations. During abalone broodstock collections, more abalone were harvested than the allowable 1% of the calculated population under the initial protocol at several sites.

As part of a precautionary approach, the recommended maximum number of abalone to be removed for broodstock is 1% of the lower 90% confidence limit on the estimated population in the size range of 81-120 mm shell length. Abalone is a threatened species and all removal of abalone from the wild should be carefully considered.

Résumé

Un protocole et une méthodologie de relevé sont utilisés depuis trois ans pour déterminer l'abondance de l'ormeau. Dans ce document, les données recueillies lors de six relevés effectués aux fins de prélèvement d'ormeaux reproducteurs sont passées en revue et utilisées afin de déterminer le taux de prélèvement approprié. Le protocole de relevé proposé et les considérations liées au prélèvement de géniteurs font l'objet de discussions.

Ces relevés offrent peu d'indices d'un rétablissement des populations d'ormeaux. Au cours des prélèvements de géniteurs effectués à différents endroits dans le cadre du protocole initial, le nombre d'ormeaux récoltés était supérieur au nombre autorisé, soit 1 % de la population estimée.

Dans le cadre de l'approche de précaution, le nombre maximal recommandé pour le prélèvement d'ormeaux reproducteurs est égal à 1 % de la limite inférieure de confiance à 90 % de l'estimation de la population dont la longueur de la coquille se situe entre 81 et 120 mm. L'ormeau est une espèce menacée et tout prélèvement de cette espèce dans la nature devrait être soigneusement étudié.

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1. Introduction

Northern, or pinto, abalone, *Haliotis kamtschatkana*, in British Columbia (BC) is currently listed as a "threatened species" ("a species likely to become endangered if limiting factors are not reversed") by the Committee on the Status of Endangered Wildlife of Canada (COSEWIC). All removals of northern abalone are considered a severe conservation risk.

As part of the strategy to rehabilitate northern abalone in BC, initial attempts are to include development of aquaculture methodology for use in stock rebuilding initiatives (Toole *et al.*, 2002). This will require removal of mature abalone from the wild from a number of areas to provide broodstock for seed production at aquaculture facilities throughout BC.

A survey protocol and methodology to determine abalone abundance have been in use for the last three years (Lucas *et al.*, 2002a,b,c,d,e). The objectives of this paper are to (1) review past broodstock surveys and (2) provide a revised protocol for abalone broodstock assessment and collection from the wild. The proposed survey protocol and broodstock removal considerations are discussed.

The revised "Broodstock Survey and Collection Protocols" are described in details in Appendix A and can be extracted from this document and used directly in the field by the proponents of the culture projects.

2. Past Broodstock Surveys

Five abalone culture projects entered into an agreement with Fisheries and Oceans Canada (DFO) to produce abalone juveniles for stock enhancement. The techniques and the technologies necessary to culture the northern abalone were to be developed by the projects and up to 50% of the juvenile abalone produced were to be made available to DFO for stock rebuilding experiments (Hiemstra and Plamondon, 2002). As a result of this program, the abalone culture projects have been part of the federal strategy for recovery of the abalone resource. As part of the agreements, the projects were allowed to collect broodstock abalone following interim guidelines provided by DFO. Under these guidelines, a transect survey was conducted before the collection of abalone took place. Density estimates were then calculated and a maximum number of abalone to be collected was provided for each culture project. The maximum number of abalone that could be collected was calculated as 1% of the lower 90% confidence limit of the population in the size range of 90-110 mm SL.

Since 1999, 6 broodstock surveys have taken place (Fig. 1). Each survey is briefly described in Table 1.

'Locations' referred to in this paper are the equivalent of 'surveys' (usually one field trip), combining all the sites. Site names, referred to in this paper, have been kept for convenience when comparing with published reports (Table 1). Sites are defined by the section of the coastline over which random transects were placed. For example, the Kitkatla location had six different sites based on names, at two islands. Five of these were separated by only a few hundreds metres and were considered as one site by Lucas *et al.* (2002b) (Fig. 2). However, during the current analysis (see section 3.3), there were significant differences between the sites on McCauley Island even though they were in close proximity (Fig. 2). For this reason these sites were treated separately in the present paper.

2.1. Field survey methods

The survey protocol followed during these six surveys is based on Cripps and Campbell (1998) and is described in Appendix A: "Transect survey". The placing of transects differed from the described protocol in three surveys. At Malcolm, transects were not placed randomly, but located approximately 75 m apart at Cormorant Island and approximately 100 m apart at Malcolm Island. In Lotbinière and in Kitkatla at Joachim Spit, the transect survey method was adapted for sampling a large shallow bay or spit. In Lotbinière, initial random positions within the bay were generated using X and Y coordinates and drawn on a nautical chart. Any potential transects falling on land or in water > 7 m depth were discarded. Each transect was 1 m wide and 20 m in length. At Joachim Spit, random transect start positions were selected along four 100 m long sections within the 0 - 12 m depth range.

2.2. Data analysis

The data analysis followed the methods described in "Analytical Methods", Appendix A. The present analysis is similar to published analytical methods (Lucas *et al.*, 2002a, b, c, d, e) except for confidence limits where we use bootstrapping (see Appendix A: Analytical methods) instead of parametric methods (Zar 1984).

Broodstock guidelines, which have been in effect since 1999, recommended taking abalone in the 90-110 mm shell length size range. These guidelines have sometimes proved impractical where there were few abalone within the proposed size range. For this reason, most of the data analysis focused on adult abalone in the size range of 80-120 mm SL to include all of the abalone likely to be collected for broodstock while leaving the potentially highly reproductive large abalone (Campbell *et al.*, 1992).

When possible, published site widths were used. These site widths were measured using Nobeltec, except for Lotbiniène where survey area was calculated using ArcView 3.2. Site widths on McCauley Island, Kitkatla, were not measured individually, but as one combined site (black line on Fig. 2). As these sites were analyzed separately in the present paper, individual site widths were measured using ArcView 3.2 (red lines on Fig. 2) and are therefore different from McCauley Island widths already published (Lucas *et al.*, 2002b).

2.3. Survey results

The results are presented by site and location only, as the transect information can be found in the published survey reports (Table 1).

Emergent abalone, at all survey locations, were more abundant between depths of 0-6m chart datum (Fig. 3). In Bamfield, abalone tended to be a little deeper (1-11m) compared to the other locations (not shown). The size frequencies for each location are presented in Fig. 4. Kitkatla survey was the most extensive, with 49 transects and 421 abalone counted and measured (Table 2; Fig. 4). Most locations showed some recruitment (defined as immature abalone ≤ 70 mm SL). Malcolm location was largely comprised of large abalone with 63% >120 mm SL and only 3% ≤ 70 mm SL (Fig. 4). All abalone counted and measured (9) at Denman Island in 2001 were in the 80-120 mm SL size range (Fig. 4).

Densities varied between locations and between sites within locations (Table 2; Fig. 5). However, density estimates at all sites were low ranging from 0.006 abalone/m^2 at DX, Bamfield, to 0.543 abalone/m^2 at HN, Kitkatla. Abalone were found in only 500 (6%) out of 7964 quadrats in all the surveys. Aggregations of 2 or more animals per quadrat were found in only 139 cases (1.7%). An ANOVA was performed to compare variability between location and between site density estimates for the 80-120 mm SL size range. There were no significant differences in mean densities between locations. Sites, within the same location, showed significant differences. A Tukey multiple comparison test (Splus 6.1, 2002) was used to discriminate between sites. In Bamfield, EEK had significantly more abalone in the 81-120 mm SL size range than DX and WEK. In Kitkatla, BB had significantly more abalone in the 81-120 mm SL size range than HP, JP and SI. HN also had significantly more abalone in the 81-120 mm SL size range than JP.

2.4. Broodstock collection to date

Table 3 summarizes population estimates, maximum number of abalone to be collected and reported number abalone collected and their subsequent mortality in culture facilities.

In total, 349 abalone have been collected by all culture projects. Bamfield and Lotbinière were the only two locations where the number of collected abalone did not exceed the number calculated for the 80-120 mm SL population, which was a larger size range than previous guidelines (90-110 mm SL). More than 70% of the collected abalone were female at all locations, except in Bamfield where females accounted for 58% of all the abalone taken. The smallest abalone collected was 81 mm SL and the largest was 144 mm SL. Except for Malcolm, the majority of abalone collected were in the recommended 90-110 mm SL range (not shown). At Malcolm, a total of 49 abalone have been collected. The majority of the abalone came from Cormorant Island (CI) and 5 abalone were collected in front of the hatchery in Sointula, a location that was not surveyed. Some animals were collected at Trinity Bay (TB) and Bere Bay (BB), but these were returned because of poor gonad conditions (spawned out). Kitkatla also had abalone (29) that were collected outside of the surveyed areas. In total, 165 abalone were collected in Kitkatla.

Of the 349 abalone collected, more than half have died in aquaculture facilities. Bamfield and Malcolm have the best record with 7% and 18% reported mortality, respectively, while at Kitkatla, more than 80% of the abalone collected have died. Kitkatla was unusual in that the broodstock collections were made several hundreds of kilometres from the culture facility in Fanny Bay, on the east side of Vancouver Island. The long transport probably contributed to the high mortality. The causes of individual death were not specified, but were likely caused by handling, crowding, temperature/salinity aberrations and/or disease during culture.

3. Discussion of the Proposed Broodstock Survey Protocol

The "Broodstock Survey Protocol" is described in detail in Appendix A.

The objective of the survey methodology is to provide a standard protocol for determining abalone size frequencies, densities and total population sizes in proposed abalone broodstock collection areas. It is expected that the proponents will do the surveys with some input from DFO (e.g., designate random transects, data analysis, and archive the data). DFO personnel are not expected to participate in the surveys. For this reason, the survey design described in Appendix A is logistically simple, as the proponents may not have the expertise to apply complicated survey designs.

Results from the broodstock surveys presented in the previous section were examined to determine the number of transects necessary to achieve adequately precise and accurate density estimates for broodstock collection.

The proposed survey protocol uses timed swims as a preliminary survey method to find suitable abalone densities that have the potential for broodstock collection followed by randomly placed transects perpendicular to the shoreline. The original transect survey method was designed by Cripps and Campbell (1998). The main proposed change to this method is the addition of timed-swims as a standardized site search.

3.1. Transect survey for density estimates

Hart *et al.* (1997) compared transect surveys with surveys based on timed-swims. They concluded that transect surveys provided accurate measures of abalone abundance and the timed-swims method exhibited only a weak relationship with absolute abundance. Timed-swims are unreliable as a measure of absolute abundance because of the influences of diver skill, environmental conditions, habitat characteristics and abalone distribution patterns (Hart *et al.* 1997; McShane 1998; Gorfine *et al.* 1997; Shepherd, 1985). However, timed-swims are useful as an exploratory method to establish presence/absence and relative abundance of abalone in an area.

The transect method has been used extensively in the Pacific region for stock assessment of shellfish resources (e.g., red sea urchin: Campbell *et al.*, 1999; sea cucumber: Hand and Rogers, 1999; geoduck: Campbell *et al*, 1996; green sea urchin: Perry and Waddell, 1999). The transect method has been chosen here because of its logistical and analytical simplicity. However, each transect is the sample unit and not each quadrat. To increase the number of transects sampled per survey, fewer quadrats within a transect could be sampled (*i.e.*, every second quadrat should be sampled and more transects laid out) (see Number of Samples section).

Dive logs from the broodstock collections indicate that abalone were collected between depths of 8-30 feet (2.5-9.5 m; not corrected for tides). During the broodstock surveys, abalone were most frequent in depths of 0-6m chart datum (Fig. 3). Adult northern abalone are usually found in depths of less than 10 m and juveniles can be found in shallow depths as well as slightly deeper than adults (Cripps and Campbell, 1998; Sloan and Breen, 1988). The transect survey methodology as described here, should be restricted to depths of less than 10 m chart datum to minimize the time spent underwater at depths where adult abalone are sparse. In some cases, transects can not be perpendicular to the shoreline if the site chosen is in a large shallow bay, on a spit or archipelago. In these cases, the start location of the transects can be randomly determined before the field survey begins and a constant transect length of 25 m could be applied (Lucas *et al.* 2002b, c).

In the transect method, as described in this paper, only emergent, or exposed, abalone are counted and boulders are not turned over to look for cryptic abalone. Sampling only exposed abalone is an efficient sampling strategy for broodstock, since the majority of mature abalone (*i.e.*, ≥70 mm SL) are exposed (Campbell 1996). In addition, counting only emergent abalone should provide a minimum estimate of mature population numbers, as cryptic adult abalone account for about 8% of surveyed abalone (Campbell, 1996).

3.2. Site selection

In general, less than 1% of the total length of the sites was surveyed (Table 2). Sites on McCauley Island, Kitkatla, were significantly different from each other even though they were close proximity of each other (Fig. 2; Table 2). This suggests that northern abalone densities fluctuate over a small spatial scale. Therefore, the width of selected sites should be accordingly small in order for the estimated mean densities to be representative of the entire site. Sites should also be small to minimize the impact of the harvest. The larger sites from all the broodstock surveys to date (Table 2) had a width of about 1.5 km. The minimal site length should be at least 500 m to minimize the chances of harvesting an isolated aggregation of abalone, as the frequency and size of patches required to maintain sufficient recruitment are unknown for northern abalone (Campbell, 2000).

Site selection can be assessed rapidly using timed-swims. In an unpublished report, Clapp *et al.* (pers. comm.) used timed swims to find suitable populations of abalone in Barkley Sound. Two dive teams surveyed 110 sites in 10 days in June 1991. A total of 1589 emergent abalone were found with a mean of 14.4 per 10 minutes swim (site). The results of the timed-swims were used to identify sites of high abalone densities suitable for the more costly transect surveys. In the Clapp *et al.* (pers. comm.) study, timed-swims with abalone counts of more than 20 per 10 minutes, or a cluster of several timed swim counts of more than 10 per 10 minutes, were chosen for subsequent transect surveys.

Timed-swims should be use as a relative index of local abundance to concentrate efforts during the transect survey. No density estimates should be calculated from timed-swims (see section 4.1 above).

3.3. Number of samples

Quadrats

In the broodstock surveys (Table 1), there were ninety transects (out of 147) where every quadrat was surveyed. In the present paper, these transects were analyzed to estimate the impact of skipping quadrats along the transect. One transect had an unusual pattern of abalone aggregations and was left out of the following analysis. To do this, transect densities were estimated from every second quadrat. Similarly, transect densities were recalculated from every 3rd, 4th and 5th quadrat. The resulting transect densities are shown in Fig. 6.

The transect densities estimated from the entire set of quadrats (89) were assumed to be correct. Each time quadrats were skipped, there was an error in estimating the transect densities. If every q^{th} quadrat was surveyed, then the error in estimating density for the t^{th} transect was $\varepsilon_{t,q}$. The mean square of error, MSE, associated with skipping quadrats was

$$\mathrm{MSE}_q = \sum_{t=1}^{89} \frac{\varepsilon_{t,q}^{2}}{89-1}$$

The results from these calculations are:

Sampling frequency (*q*)	MSE_q
1	0
2	0.0056
3	0.0186
4	0.0200
5	0.0281

MSE_3 is more than 3 times that of MSE_2. An ANOVA was performed to calculate transect-to-transect variance (each transect weighted equally) in order to put the contribution of the impact of skipping quadrat in perspective. The transect-to-transect MSE was 0.0588. The estimated mean site density was less accurate if quadrats were skipped, but the error could be regained by surveying more transects. This analysis predicts that if every second quadrat is skipped and the number of surveyed transects is increased by 8%, the standard error of the site means would stay about the same.

The time spent setting up a transect is usually small compared to the time required to complete the transect. To increase the number of transects, *i.e.* samples, every second quadrat should be sampled completely in order to minimize the underwater time while maximizing the number of samples. An alternative to skipping quadrats, would be to count and measure abalone in every quadrat, but record substrate and algae cover in every second or fourth quadrat. For extremely long transects, this could also be in conjunction with skipping quadrat. The proposed broodstock survey protocol combined all of these approaches by setting the quadrat sampling frequency as a function of transect length (known when transects are laid out from the boat).

Transects

The precision and reliability of the estimated densities for each site will improve as the number of transects increases. Table 2 gives the number of transects, and mean and associated standard error for 81-120 mm SL abalone. The standard error and the number of transects can be used to predict the standard error for different numbers of transects. Figure 7 shows how the coefficient of variation (CV) is affected by sample size. A similar analysis was done to examine the effect of N on *L90%CI* of the mean (Fig. 7).

In general, at a low mean density estimate, the CV becomes asymptotic at a higher value. There are exceptions. For example, Hankin (HP), Kitkatla, and Trinity Bay (TB), Malcolm, become asymptotic at low CV, around 0.2 (Fig. 7), but they have very low density estimates and a sample size of 50 transects will not provide densities necessary for broodstock collection (Fig. 7). For most sites, the curves usually started to become asymptotic at about 10 transects per site after which the addition of more transects has a relatively small impact on precision.

To obtain precise and accurate abalone density estimates, future broodstock surveys should have at least 10 transects per site and if every second quadrat is skipped (see section 4.3.1), 11 transects per site should be used.

4. Discussion of the Proposed Broodstock Collection Protocol

The “Broodstock Collection Protocol” is described in detail in Appendix A.

4.1.Size of abalone

Campbell *et al.* (1992) is the only published study of fecundity in wild northern abalone populations in BC. They 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. There was no indication that large northern abalone females became senile with decreased egg production. From cumulative size frequency of abalone surveyed of eastern Moresby Island during June 1990 (Thomas *et al.*, 1990), Campbell *et al.* (1992) estimated that 50% of the total potential eggs would 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 would produce 50% of the total potential egg production. They concluded that large females are essential in contributing eggs to the total potential egg production.

To obtain the highest egg return at the hatchery without depleting the large sized abalone stock, abalone collected for broodstock should be in the range of 81-120 mm SL. Abalone larger than 120 mm SL should not be collected, therefore leaving the potentially highly reproductive large abalone (Campbell *et al.*, 1992).

4.2.Recruitment and the importance of patch size

Close scrutiny of past broodstock collections, revealed that divers concentrated their collection effort in very small areas, usually at the surveyed transects where the highest number of abalone had been counted. For example, in Kitkatla 49 transects were surveyed in seven sites. Abalone were collected from three of these sites. Records show that most broodstock abalone were taken near the fourteen transects (out of 27) with the highest abalone counts for these sites. This is not to say that only transect counts should be used for abalone broodstock collection, but it illustrates that only patches are, in reality, harvested. These aggregations are believed to enhance reproductive success 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). Recent studies in abalone (McShane 1995a, 1995b; Shepherd and Partington, 1995; Babcock and Keesing, 1999) 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. Because fertilization success depends on the aggregation density of abalone, broodstock collection of most animals in an aggregation may reduce production of larvae (Campbell, 2000) and should be avoided. We suggest that during broodstock collection, the divers disperse their collection effort by counting nine abalone of the selected size range (81-120 mm SL) and collecting the tenth.

It is hard to infer, from published literature, a minimum density under which no abalone should be removed to prevent reduced reproductive potential due to rarity, known as the Allee effect (Allee *et al.* 1949). Shepherd and Brown (1993) observed a 50% decline in the proportion of aggregating adults in *H. laevigata* when density declined from 1.8 to 0.7/m^2. They reasoned that the loss of reproductive potential is multiplied by a factor related to the ability of abalone to aggregate. In other words, the effective population size (the population contributing to the next generation) declines more rapidly than the true population size as density declines. In the same study, a mean density change from 0.37 to 0.29 in 13 years was followed by a recruitment failure (Shepherd and Brown, 1993). Shepherd and Partington (1995) showed that there was critical stock density threshold (0.15-0.20 abalone/m2) for *H. laevigata*, below which the risk of recruitment failure was high. For *H. kamtschatkana*, Breen (1986) suggested prerecruit (92-99 mm SL) and new recruit (100-106 mm SL) densities of $0.55/m^2$ and $0.45/m^2$, respectively, as replacement requirement densities. Campbell (1997) suggested densities $0.26/m^2$ for prerecruit and $0.14/m^2$ for new recruit would be required for the reopening of the fishery in BC.

In the broodstock surveys, the highest density for the 81-120 mm SL size range was $0.263/m^2$ (Table 2), which is well below the densities suggested by both Campbell (1997) and Breen (1986). However, in Campbell (1997), the suggested the required densities for the reopening of the fishery were set arbitrarily at slightly higher than 50% of the peak densities during the late 1970s. In Breen (1986), the estimated required replacement densities were based on a stock-reduction model for the whole North Coast area and might not be representative of small abalone stocks. Nevertheless, these critical densities for the northern abalone, as well as for other species, indicate that extreme caution should be exercised for broodstock collections.

Since part of the strategy to rehabilitate northern abalone in BC (Toole *et al.*, 2002) requires the removal of mature abalone from the wild to provide broodstock for seed production, broodstock collections may be justified. However, given the variable success of enhancement through seed transplant in other parts of the world (McCormick, 2000; Tegner, 2000), the number abalone collected for broodstock should be kept to a minimum until such time when enhancement through seed production is proven an effective method for northern abalone stock rebuilding.

4.3.Maximum number of abalone to be collected

In general, when the slope of the CV becomes asymptotic at relatively high values (Fig. 7), the predicted *L90%CI* densities remain small (Fig. 7). Consequently, the maximum number of abalone that can be removed from one site when precision is low will be relatively small (Table 3) depending on the site area measurement.

The area of each site is calculated as the site width multiplied by the mean transect length. Two other methods for estimating site area were evaluated using ArcView 3.2 and digital nautical chart. Two sites, east Edward King Island (EEK) and Aguilar Point (AP), in the Bamfield broodstock survey, were used for this evaluation. These sites have a calculated area, as described above, of 9.0 km^2 and 1.6 km^2, respectively (Table 2). First, the area between 0-10 m chart datum was calculated using chart depth contours. The resulting areas were 13.7 km^2 for EEK and 3.28 km^2 for AP. The second method measured the coastline of these two sites. The resulting coastline lengths were 3,032 m for EEK and 358 m for AP, which, when multiplied by mean transect lengths, give area estimates of 18.2 km^2 and 2.2 km^2. Both methods resulted in larger site area estimate than what was estimated using the site width and mean transect length (Table 2). Using the site and mean transect length is therefore more conservative. A third method was also investigated in which the coordinates of each transect are use to mark the end of the abalone 'area'. This proved impractical where the coastline is convoluted with a steep slope, which is one of the preferred habitats of abalone.

Considering the threatened status of this species, the exploitation rate should be correspondingly low. Using a risk-averse approach, we arbitrarily recommend that less than 1% of the lower 90% confidence limit of the estimated mature population (*i.e.*, 81-120 mm SL) should be collected for broodstock at each selected site. Where 1% of the *L90%CI* is less than 20 abalone individuals, no abalone should be removed.

4.4.Genetic consideration for future juvenile outplants

The planktonic phase of the northern abalone is short (less than 2 weeks) (Sloan and Breen, 1988). Abalone larvae are non-feeding and are poor swimmers. For these reasons, it has been suggested by many authors that larvae dispersal is minimal and that recruitment is from local populations (Shepherd and Brown, 1993; Tegner, 1993; Tegner and Butler, 1985; Prince *et al.*, 1987; McShane *et al.*, 1988; McShane 1992, 1995a, 1995b). This contrast from genetics studies which found high genetic variation indicating gene flow over large areas with little population subdivision (Brown 1991; Brown and Murray, 1992, Shepherd and Brown, 1993; Burton and Tegner, 2000; Withler *et al.*, 2001). The stock-recruitment relationships for the northern abalone are unknown.

To insure the safeguarding of 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 location to provide adequate genetic diversity (Templeton, 1990).

4.5.Timing and frequency of collection

Campbell *et al.* (1992) found that 90% of females were in, or close to, the ripe stage during the first half of June near Moresby Island suggesting imminent spawning. Breen and Adkins (1980), also off Moresby Island, found spawning adult abalone aggregations during July. Quayle (1971) found peak proportion of post-spawned abalone from April to June in Tofino. Emmett and Johnstone (1985) found gonad indices were the highest during summer (possible June-August spawning) and lowest during fall-winter in Barkley Sound. All these studies indicated that most northern abalone spawn mainly in early to mid-summer in BC. The broodstock collection trips at Malcolm were in late August-early September and there were reports of spawned out abalone.

Wild adult abalone may be ready to spawn immediately following collections, but more reliable results are obtained when they are conditioned for several weeks or months (McCormick, 2000). Collection should be 2-3 months before spawning. This will give ample time to condition the abalone and optimize egg and sperm yield. Therefore, collections should take place in late winter and spring before the abalone gonads become ripe in the summer.

5. Conclusion

Although cryptic abalone were not searched for in these surveys, all locations showed some recruitment (abalone < 70 mm SL), especially in the north coast area (Kitkatla and Lotbinière) (Fig. 4). Overall, estimated densities were low. These surveys provide little evidence of recovery of abalone populations.

There were serious problems with broodstock collections. In Kitkatla and to a lesser extent in Malcolm, abalone were collected outside of surveyed areas. All broodstock abalone were tagged, but none have yet been returned to the original collection site. Although the calculations of allowable numbers of abalone to be collected presented in this paper are for a wider range (81-120 mm SL) than was previously recommended (90-110 mm SL), more abalone were harvested than was calculated at several sites (Table 3). Future broodstock collections should be closely monitored to avoid these problems. Aquaculture facilities should be audited on a regular basis to try to avoid the high mortality reported. If broodstock survey and collection protocols are not followed, project proponents should lose their privilege to collect broodstock, permanently or until such time when the problem has been resolved.

If we assume that broodstock abalone will eventually be returned to the collection site, then the survival of these abalone should be monitored using the transect survey methodology described in Appendix A. In addition, the selected sites should be monitored to assess the impact of broodstock harvesting. To reduce impact of disease transmission, all transfer of abalone to and from the wild should be certified as disease free by the federal/provincial Introductions and Transfers committee.

There is considerable uncertainty of the stock recruitment relationship of northern abalone. The importance of factors such as the spatial frequency, patch size and density, and environmental conditions required to maintain sufficient recruitment for healthy northern abalone populations are unknown. Consequently, a precautionary approach should include using the approximate lower 90 % confidence limit of the mean of the mature population estimate (81-120 mm SL) when calculating the potential number of abalone (*i.e.*, < 1 % of estimated population) to be removed for broodstock. The short-term objective of the National Recovery Strategy for the Northern Abalone (Toole *et al.* 2002) is to halt the decline of abalone populations in BC. Therefore, at any given site, abalone have to be in sufficient quantities that a portion of the population can be harvested without further depletion.

Abalone is a threatened species and all removal of abalone from the wild should be carefully considered.

6. Recommendations

1. **Follow the survey and broodstock collection protocols as described in Appendix A.** Surveys for abalone abundance and distribution using initial exploratory timed swims to select sites of good abalone density followed by a minimum of 10 transects surveyed for each selected site. Sites should be small for the estimated mean densities to be representative of the entire site and also to minimize the impact of the harvest on the local abalone stock.
2. **The maximum number of abalone that can be removed from any given site should be less than 1% of the lower 90% confidence limit of the mature abalone population (80-120 mm SL) estimated at that site.**
3. Broodstock surveys and collections should be supervised by DFO personnel or a biological monitor approved by DFO. All data should be forwarded to DFO Stock Assessment for analyses and archiving.

4. The number of abalone collected for broodstock should be kept to a minimum until such time when enhancement through seed production is proven an effective method for stocks rebuilding of northern abalone.
5. The selected sites should be monitored to assess the impact of broodstock harvesting and the survival of broodstock abalone returned to their original collection site.

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8. References

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

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

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 B.E. Adkins. 1980. Observations of abalone populations in Emily Carr Inlet and Lotbinière Bay, April 1980. Can. MS Rep. Fish. Aquat. Sci. **1576**: 17 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 N.D. Murray. 1992. Population genetics, gene flow, and stock structure in *Haliotis rubra* and *Haliotis laevigata*. pp. 24-33 *In* Shepherd, S.A., M.J., Tegner, S.A., Guzmán del Próo (eds), Abalone of the World - Biology, Fisheries and Culture. Fishing News Books, Oxford.

Burton, R.S., and M.J. Tegner. 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. 1996. An evaluation of abalone surveys off southeast Queen Charlotte Island. Can. Tech. Rep. Fish. Aquat. Sci. **2089**: 111-131.

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. Public. Fish. Aquat. Sci. **130**: 41-50.

Campbell, A., W. Hajas, and D. Bureau. 1999. Quota options for the red sea urchin fishery in British Columbia for fishing season 2000/2001. DFO Can. Stock Assess. Sec. Res. Doc. **1999/201**: 35 p.

Campbell, A., C.M. Hand, C. Paltiel, K.N. Rajwani, and C.J. Schwarz. 1996. Evaluation of some survey methods for geoduck. Can. Tech. Rep. Fish. Aquat. Sci. **2221**: 5-42

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

Clapp, B., A. Campbell, G.S. Jamieson, and P. Ridings. Unpublished report. Preliminary survey of northern abalone populations in Barkley Sound, British Columbia, 1991.

Cripps, K., and A. Campbell. 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.

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

Emmett, B., and D. Johnstone. 1985. An experimental abalone transplant in Barkley Sound, British Columbia. Report prepared by Archipelago Marine Research and the West Coast Abalone Harvester's Association, Victoria, BC, for Fisheries and Oceans Canada. 65 p.

Gorfine, H.K., D.A. Forbes, and A.S. Gason. 1997. A comparison of two underwater census methods for estimating the abundance of the commercially important blacklip abalone, *Haliotis rubra*. Fishery Bulletin **96**: 438-450.

Hand, C.M., and J. Rogers. 1999. Sea Cucumber Phase 1 Fishery Progress Report. DFO Can. Stock Assess. Sec. Res. Doc. **1999/141**: 26 p.

Hart, A.M., H.K. Gorfine, and M.P. Callan. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) I. An analysis of diver-survey methods used for large-scale monitoring. Fish. Res. **29**: 159-169.

Hiemstra, L., and N. Plamondon. 2002. Proceedings of the meeting between Fisheries and Oceans Canada and representatives of the abalone culture projects. April 23-24, 2002, Nanaimo, BC. 40 p.

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

Lucas, B.G., D. Brouwer, and A. Campbell. 2002a. Survey of northern abalone, *Haliotis kamtschatkana*, populations at Malcolm Island and Cormorant Island, British Columbia, October 1999. [Revised]. Can. MS Rep. Fish. Aquat. Sci. **2620**: 10 p.

Lucas, B.G., D. Brouwer, and A. Campbell. 2002b. Survey of northern abalone, *Haliotis kamtschatkana*, populations near Kitkatla, British Columbia, March 2000. [Revised]. Can. MS Rep. Fish. Aquat. Sci. **2622**: 11 p.

Lucas, B.G., A. Campbell, and D. Brouwer. 2002c. Survey of northern abalone, *Haliotis kamtschatkana*, populations in Lotbinière Bay, British Columbia, March 2000. [Revised]. Can. MS Rep. Fish. Aquat. Sci. **2621**: 10 p.

Lucas, B.G., A. Campbell, and D. Brouwer. 2002d. Survey of northern abalone, *Haliotis kamtschatkana*, populations at Chrome and southern Denman Island areas, May - June 2000 and May 2001. Can. MS Rep. Fish. Aquat. Sci. **2624**: 13 p.

Lucas, B.G., A. Campbell, D. Brouwer, S. Servant, and N. Webb. 2002e. Survey of northern abalone, *Haliotis kamtschatkana*, populations in southeast Barkley Sound, British Columbia, July 2000. [Revised]. Can. MS Rep. Fish. Aquat. Sci. **2623**: 11 p.

McCormick, T. 2000. Abalone (*Haliotis* spp.) aquaculture: present status and a stock enhancement tool. Can. Spec. Public. Fish. Aquat. Sci. **130**: 55-60.

McShane, P.E. 1992. Early life history of abalone: a review. pp. 120-138 *In* Shepherd, S.A., M.J., Tegner, S.A., Guzmán del Próo (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. 1998. Assessing stocks of abalone (*Haliotis* spp.): methods and constraints. Can. Spec. Public. Fish. Aquat. Sci. **125**: 41-48.

McShane, P.E., K.P. Black, and M.G. Smith. 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.

Perry, R.I., and B.J. Waddell. 1999. Review of the fishery and assessment of green sea urchin stocks in British Columbia, with quota recommendations for 1999/2000. DFO Can. Stock Assess. Sec. Res. Doc. **1999/113**: 43 p.

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

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 J.D. Ballou. 1992. Managing genetic diversity in captive breeding and reintroduction programs. Trans. 57th N. Am. Wildl. Nat. Res. Conf. pp. 263-282.

Shepherd, S.A. 1985. Power and efficiency of a research diver, with a description of a rapid underwater measuring gauge: their use in measuring recruitment and density of an abalone population. pp. 263-272, *In* Mitchell, C.T. (ed), Diving for Science. American Academy of Underwater Science, La Jolla, CA.

Shepherd, S.A., and L.D. Brown. 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 D. Partington. 1995. Studies on southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. Marine and Freshwater Research **46**: 669-680.

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

Splus 6.1. 2002. Splus 6 Guide to Statistics. Volume 1. Insightful Corporation.

Tegner, M.J. 1993. Southern California abalone: 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 R.A. Butler. 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.

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.A., S. Farlinger, and W. Carolsfeld. 1990. Abalone resurvey in the southeast Queen Charlotte Islands in 1990. Can. MS Rep. Fish. Aquat. Sci. **2099**: 66-84.

Toole, J., B. Adkins, E. Bornhold, J. Boutillier, G. Caine, A. Campbell, A. Castledine, L. Convey, C. Cote, P. Coulson, T. Down, K. Francis, H. Gill, R. Harbo, H. Holmes, B. Jubinville, D. Lawseth, B. Lucas, A. Morgan, G. Parker, and J. Rogers. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in British Columbia. National Recovery Strategy No. XX. Recovery of Nationally Endangered Wildlife (RENEW). Ottawa, Ontario. 22 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 CSAS Res. Doc. **2001/097**: 27 p.

Zar, J.H. 1984. Biostatistical Analysis. 2nd edition. Prentice-Hall, New Jersey

Table 1. Survey description. See Figure 1 for surveys' general location.

Survey	Date	PFMA	Number of Transects	Number of Sites	Site Location	Reference
Malcolm	Oct 5-7, 1999	12	19	3	- CI: NW Cormorant Is - BB: Bere Bay, Malcolm Is - TT: Trinity Bay, Malcolm Is	Lucas *et al.*, 2002a
Lotbinière	Mar 23-27, 2000	6	25	1	- LB: Lotbinière Bay	Lucas *et al.*, 2002c
Kitkatla	Mar 14-21, 2000	5	49	6	- BB: Baird Pt, NW McCauley Is - BR: Baird Rk, NW McCauley Is - HN: Hankin Pt, NW McCauley Is - HP: Hankin, NW McCauley Is - SI: Sheldon It, NW McCauley Is - JP: Joachim Spit, Goshen Is	Lucas *et al.*, 2002b
Bamfield	Jul 5-7, 2000	23	33	4	- AP: Aguilar Pt - DX: Dixon Is - EEK: E Edward King Is - WEK: W Edward King Is	Lucas *et al.*, 2002e
Denman 2000	Jun 1, 2000	14	15	2	- CI: Chrome Is - DI: S Denman Is	Lucas *et al.*, 2002d
Denman 2001	May 29, 2001	14	6	1	- W Denman Is	Lucas *et al.*, 2002d

Table 2. Summary results for each site of the broodstock surveys. SEM = standard error of the mean; CI = confidence limit; N = sample size, number of transects. Site density estimates followed by the same letter ([a, b, c, d, e, or f]) were significantly ($p < 0.05$) different from each other, by post hoc Tukey multiple comparison analysis. See Table 1 for site abbreviations.

		Site Density estimates for all abalone			Site Density estimates for abalone 81-120 mm SL						
Site	N	Mean	SEM	Low 90%CI	Mean	SEM	Low 90%CI	Site width (m)	Mean Transect Length (m)	Area (km^2)	% of site surveyed
Malcolm											
BB	8	0.045	0.022	0.015	0.005	0.003	0.001	1,200	99.9	11.99	0.7%
CI	7	0.050	0.019	0.025	0.027	0.012	0.011	1,100	64.1	7.05	0.6%
TB	4	0.026	0.005	0.015	0.007	0.003	0.003	850	185.0	15.73	0.5%
all sites	19	0.038	0.010		0.011	0.003		3,150	104.6	32.95	0.6%
Lotbinière											
LB	25	0.264	0.069	0.156	0.132	0.033	0.082	N/A	20.0	6.27	0.8%
Kitkatla											
BB	7	0.419	0.150	0.194	0.263[c,d,e]	0.097	0.110	1,320	50.4	6.65	0.5%
BR	2	0.013	0.016	0.000	0.006	0.008	0.000	400	78.0	3.12	0.5%
HN	4	0.543	0.276	0.197	0.225[f]	0.125	0.056	820	32.3	2.64	0.5%
HP	12	0.087	0.032	0.044	0.058[c]	0.017	0.034	1,570	68.6	10.77	0.8%
SI	8	0.088	0.040	0.034	0.044[e]	0.022	0.014	950	62.5	5.94	0.8%
JP	16	0.048	0.014	0.028	0.020[d,f]	0.006	0.011	2,000	109.6	21.92	0.8%
all sites	49	0.060	0.027		0.024	0.016		7,060	75.8	53.51	0.7%
Bamfield											
AP	5	0.070	0.029	0.034	0.057	0.026	0.021	250	61.8	1.55	2.0%
DX	6	0.006	0.006	0.000	0.006[a]	0.006	0.000	730	59.0	4.31	0.8%
EEK	11	0.232	0.050	0.154	0.176[a, b]	0.045	0.109	1,500	59.9	8.99	0.7%
WEK	11	0.056	0.035	0.013	0.036[b]	0.022	0.005	1,500	92.5	13.88	0.7%
all sites	33	0.100	0.025		0.073	0.019		3,980	70.9	28.22	0.8%
Denman 2000											
CI	5	0.077	0.025	0.024	0.039	0.019	0.000	300	92.6	2.78	1.7%
DI	10	0.048	0.024	0.015	0.022	0.015	0.002	1,100	90.2	9.92	0.9%
all sites	15	0.058	0.018		0.028	0.012		1,400	91.0	12.74	1.1%
Denman 2001											
DI	6	0.049	0.028	0.011	0.049	0.028	0.011	1,800	60.5	10.89	0.3%

Table 3. Lower 90% CI population estimates of emergent abalone from the broodstock surveys and summary results of the broodstock collections. [1] Numbers in brackets are the number of females and males collected. * reported mortality for all broodstock collected at Denman (52 abalone total).

Site	Total Population all sizes	Population 81-120 mm SL	1% of population 81-120 mm SL	Broodstock collected [1]	Broodstock size range	Reported mortalities
Malcolm 1999						
BB	1,807	135	1			
CI	1,792	788	8	44 (38:6)	81-144	
TB	2,419	437	4			
out of surveyed area				5 (2:3)	91-144	
Total	6,018	1,359	14	49 (40:9)	81-144	9 (18%)
Lotbinière 2000						
LB	9,775	5,141	51	30 (21:9)	90-110	18 (60%)
Kitkatla 2000						
BB	12,939	7,321	73	60 (43:17)	90-125	
BR	0	0	0			
HN	5,215	1,490	15	49 (49:0)	86-113	
HP	4,703	3,651	37			
SI	2,047	804	8			
JP	6,031	2,400	24	27 (27:0)	88-110	
out of surveyed area				29 (29:0)	89-122	
Total	30,934	15,666	157	165 (148:17)	86-125	133 (81%)
Bamfield 2000						
AP	533	329	3			
DX	0	0	0			
EEK	13,820	9,758	98	53 (31:22)	86-113	
WEK	1,836	720	7			
Total	16,189	10,806	108	53 (31:22)	86-113	4 (7%)
Denman 2000						
CI	670	0	0			
DI	1,452	227	2	20 (14:6)	91-110	
Total	2,122	227	2	20 (14:6)	91-110	
Denman 2001						
DI	1,220	1,194	12	32 (24:8)	90-128	33 (63%)*
Total				**349 (278:71)**	**81-144**	**197 (56%)**

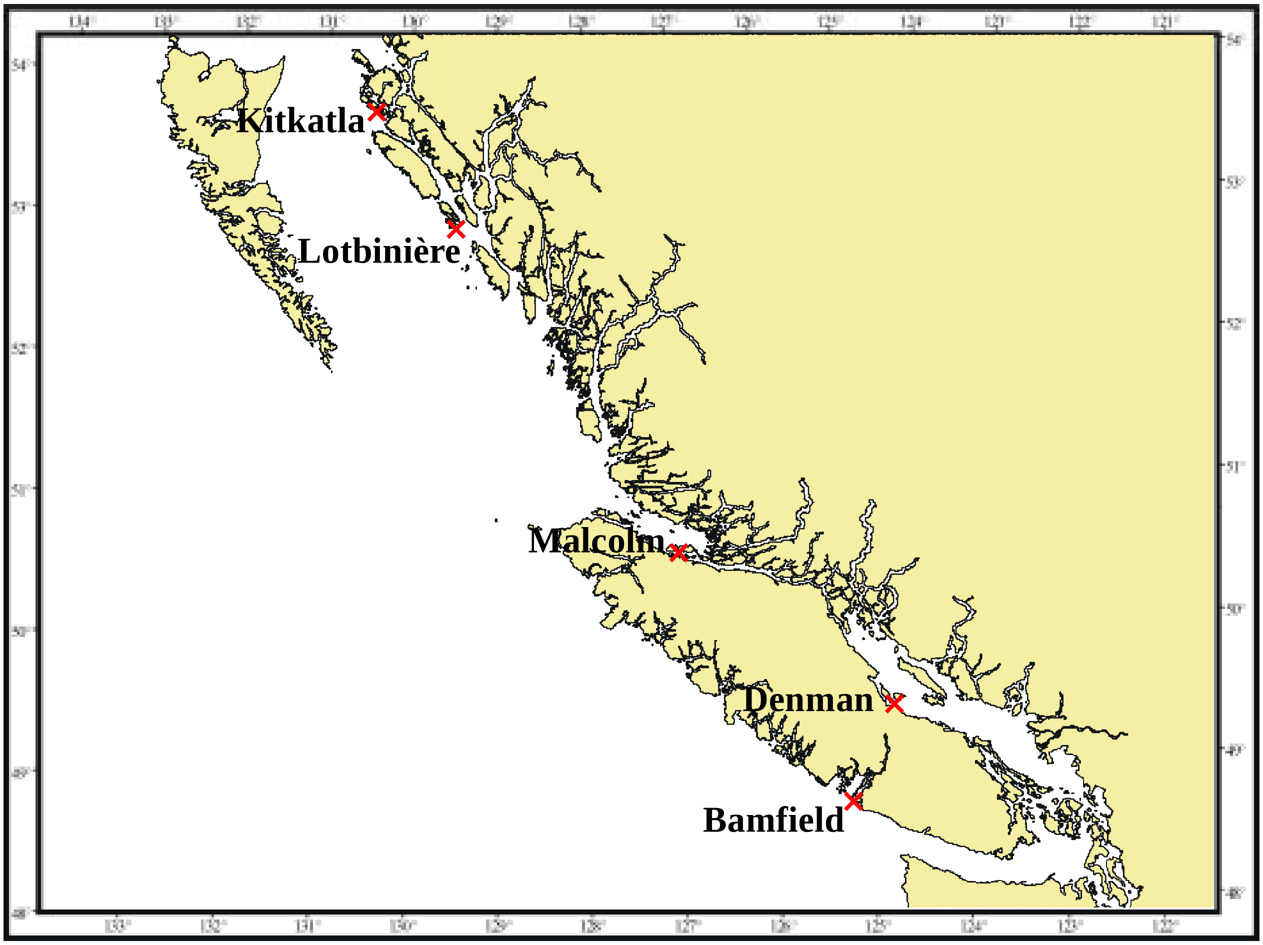


Figure 1. Abalone broodstock survey locations.

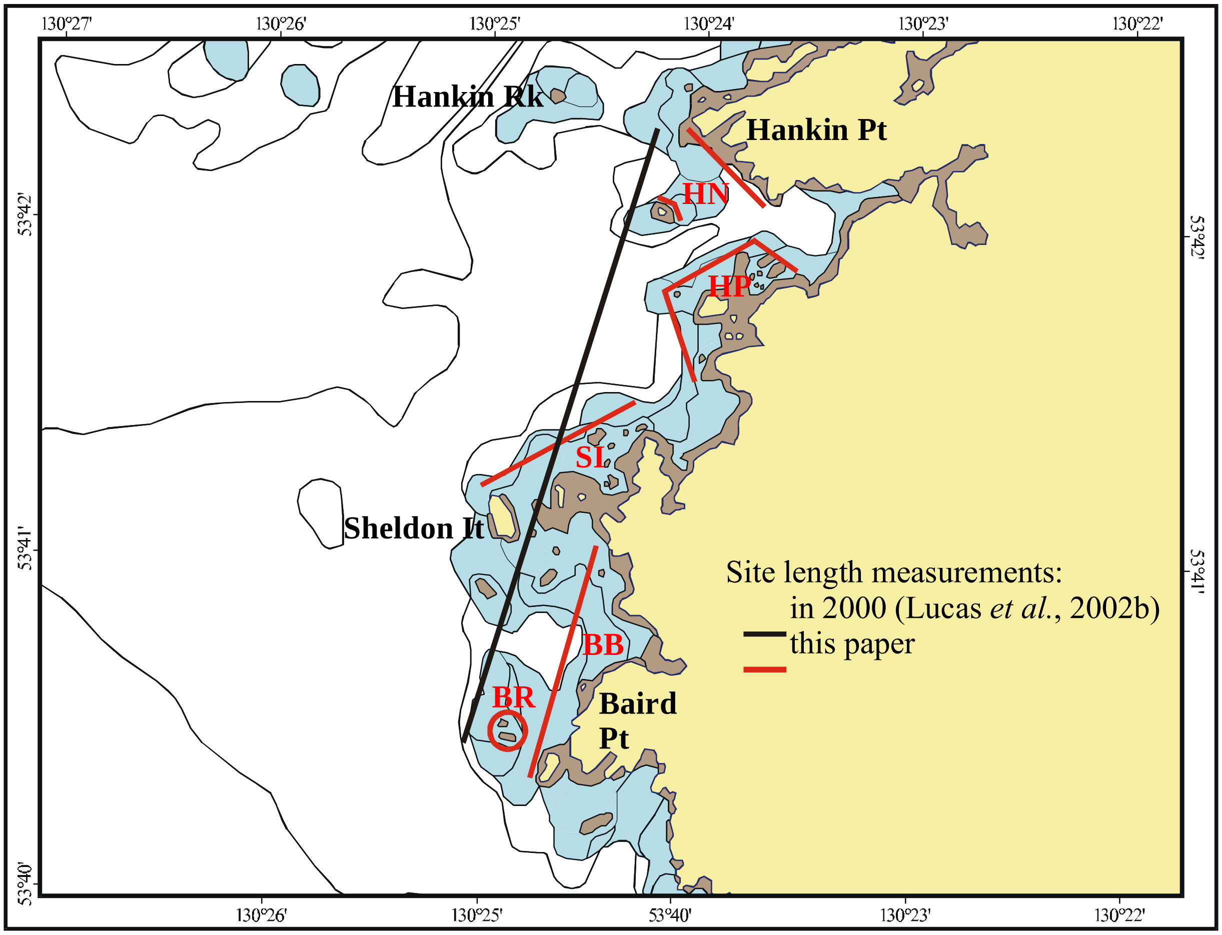


Figure 2. Sites surveyed at McCauley Island, Kitkatla broodstock survey.

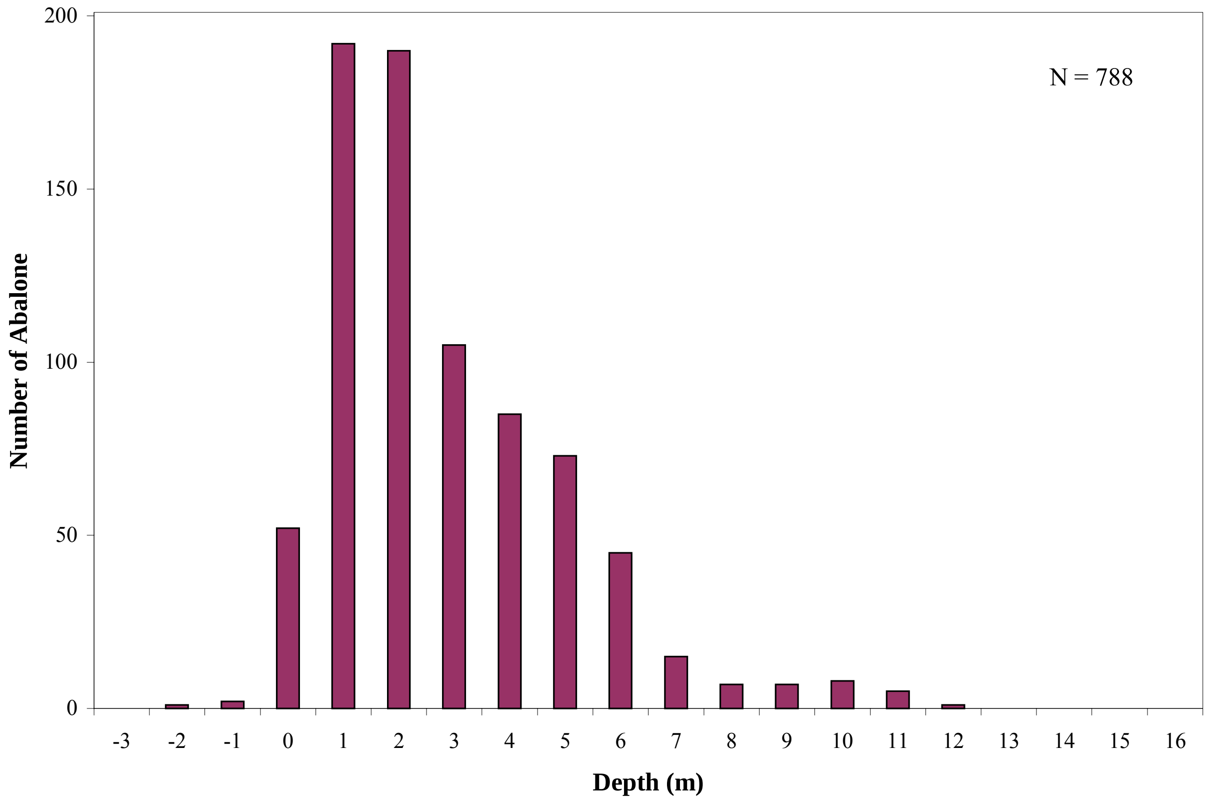


Figure 3. Number of abalone recorded in the broodstock surveys by depth categories.

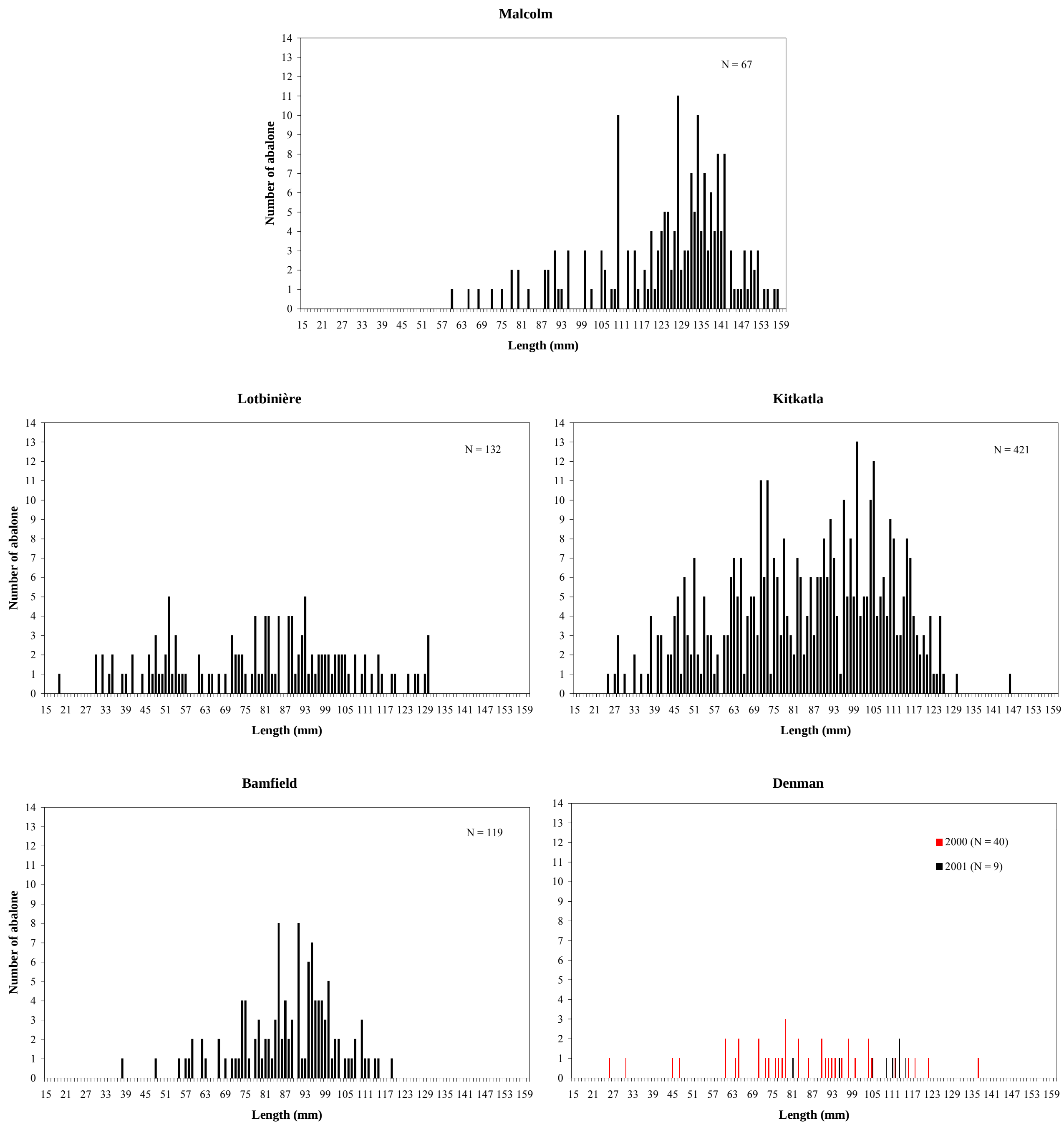


Figure 4. Size-frequencies of emergent abalone found in quadrats during broodstock dive surveys.

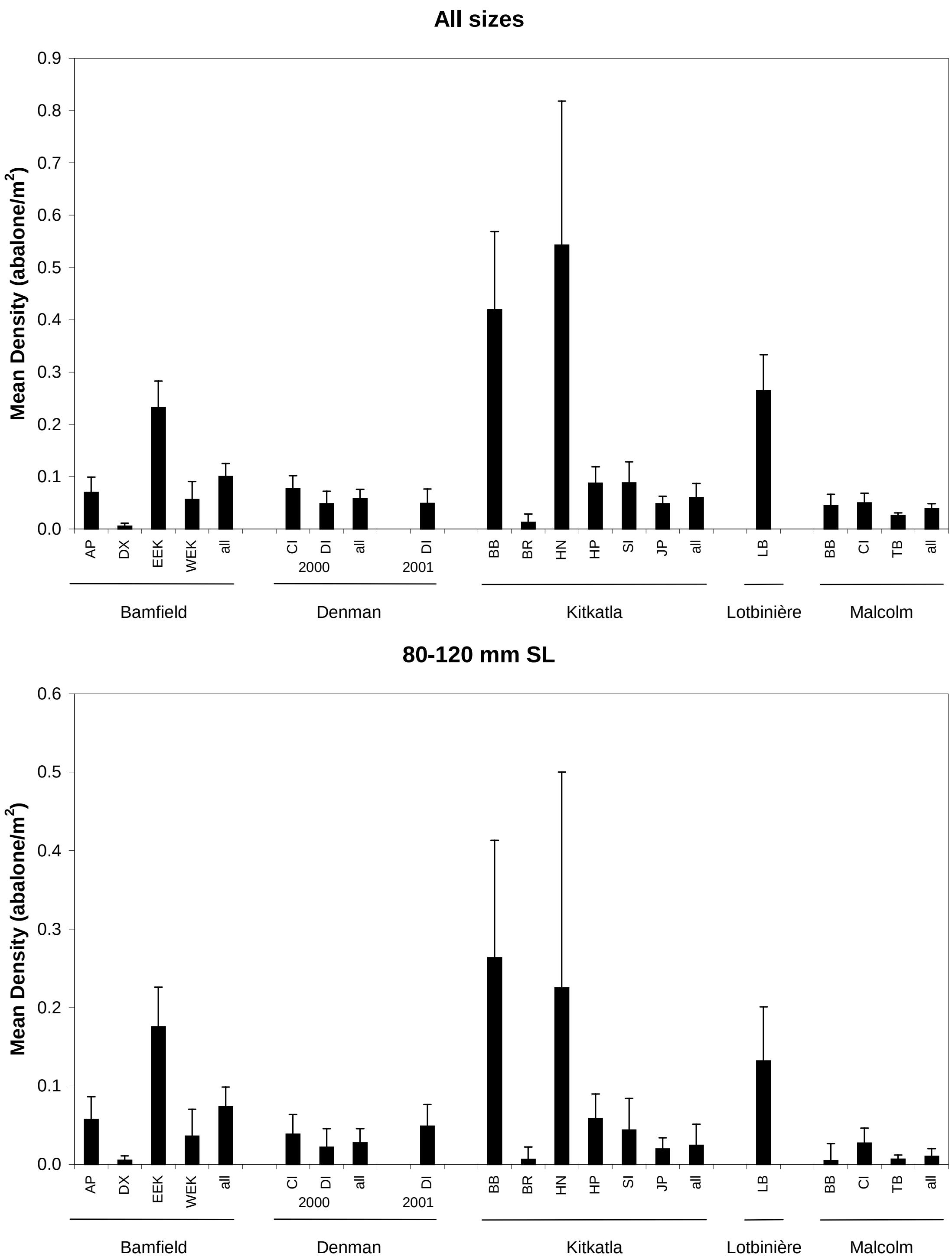


Figure 5. Abalone mean density estimates, with standard error bars, for all sizes (top) and for size range 80-120 mm SL (bottom) from broodstock surveys. See Table 1 for site abbreviations.

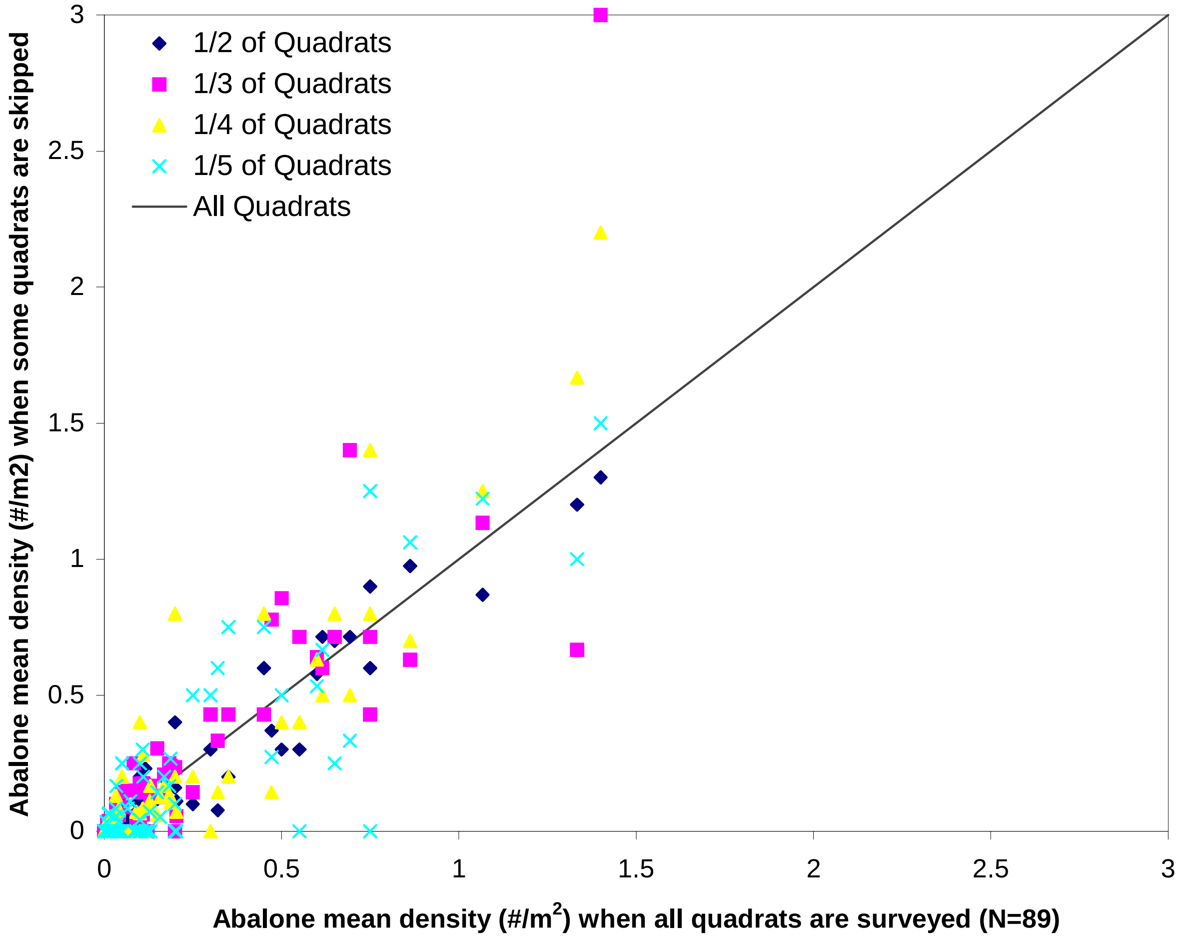


Figure 6. Effect of skipping quadrats on variability.

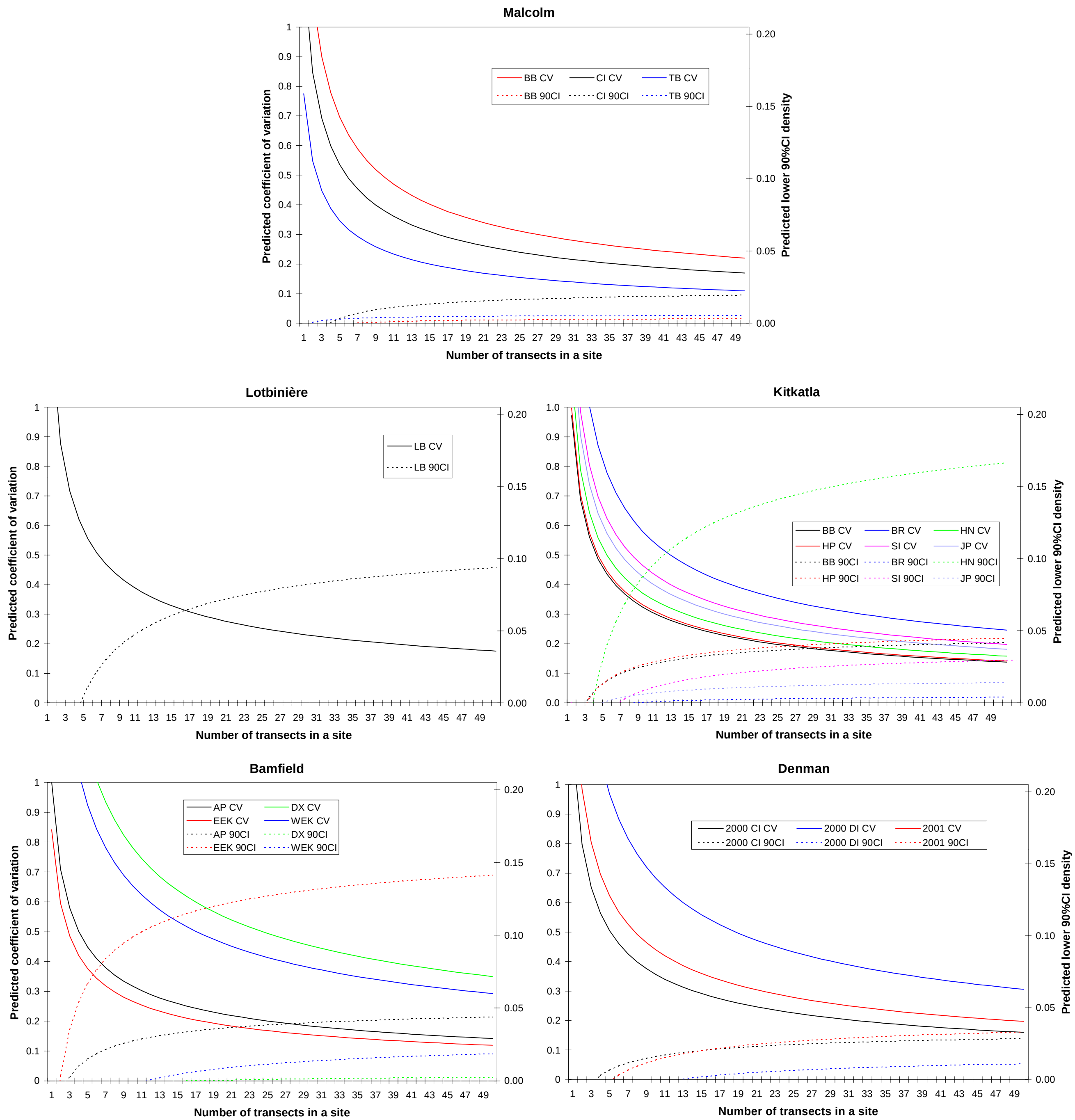


Figure 7. Relationship between the predicted coefficient of variance (CV), as a measure of precision, (left axis, solid lines) and the predicted lower 90% confidence limit of the mean (90CI) (right axis, dotted lines) estimated for the 81-120 mm SL size range and the number of transects. See Table 1 for site abbreviations.

Appendix A: Broodstock Survey and Collection Protocols

Each survey is conducted by SCUBA divers and attended by either a DFO diver, or by an DFO-certified biological monitor with diving capability. Templates of blank field sheet and a Microsoft Access database containing the electronic data entry forms will be distributed to each project before the surveys.

Based on previous surveys, two dive teams (two divers and a dive tender per team) should be able to complete between 6-10 transects per day. A survey of two sites with 10 transects per site should take 3 to 5 days. This includes at least one day for timed-swim searches.

1. Broodstock Survey Protocol

Transect surveys are time consuming and expensive. Several transects are necessary in each site to obtain a reliable density estimate. In addition, abalone have to be in sufficient quantities that a portion of the population can be harvested without further depletion. For these reasons, the present survey protocol uses timed-swims to find appropriate sites followed by a minimum of 10 transects at 2 sites (minimum of 20 transects total) to get a precise and accurate density estimate at each site.

1.1. Site selection

Potential collection sites with abundant abalone should be selected in consultation with local communities and other stakeholders. Broodstock collection should be undertaken in an area that is not at risk of population depletion through illegal harvesting. Each potential site can be assessed rapidly using timed-swims.

Timed-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, and count all the abalone seen over a 10 minute period. When counts from both divers are higher than 20, the site can be used for a transect survey. Figure 1 in Appendix B gives an example of a filled data sheet that is to be completed at each site.

Site definition

The site is defined by using landmarks and geographic coordinates. The '**site width**' is the linear distance between the two furthest points and should be at least 0.5 km and no more than 1.5 km wide. At least two sites should be selected for the transect surveys. Sites selection and definition are to be approved by DFO Stock Assessment.

1.2. Transect survey

Transect placement (in consultation with DFO Stock Assessment)

Transect positions are marked on nautical charts before the survey begins. The positions are selected randomly using the site width. Transects are perpendicular to the shoreline at these positions. At least ten transects are surveyed at each site.

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 (underwater)")

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 measures the abalone and flips the quadrat. For each quadrat, the recording diver writes down the shell length (SL in mm) of each "emergent" or "exposed" (visible on rocks) abalone, 2) the depth, 3) the substrate type, and 4) the % cover and dominant species of algae. Figure 2 in Appendix B gives an example of a filled data sheet. Appendix C lists the substrate and algae species codes to be used. The measuring diver must exercise caution when measuring abalone to ensure the longest shell length (see Fig. 1 and 2, in Appendix D) and return the abalone 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 (for an example of a filled data sheet using this sampling frequency, see Fig. 3, Appendix B). 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 (for an example of a filled data sheet using this sampling frequency, see Fig. 4, Appendix B). The frequency of sampling must be written on the underwater sheet.

1.3. 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 *site width* as defined in "1.1 Site Selection".

The expression $\sqrt{1-\frac{n}{T}}$ is nearly equal to one, because the sample size n is usually small compared to T. 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.* 81-120 mm SL), the value c_t is substituted with c_{ti}, the counts of size group i in transect t.

At each site, the lower 90% confidence intervals of the mean density (*L90CI*), for all sizes or for a particular size group (81-120 mm SL) of abalone, are calculated using bootstrapping (Davidson and Hinkley, 1997).

The estimated total number of abalone at each site (X), the population, is calculated as:

$$X = L90CI * A \qquad (3)$$

where A is the estimated area (m^2) of the surveyed site and is calculated as:

$$\bar{L} * T \qquad (4)$$

2. Broodstock Collection Protocol

The maximum number of abalone that can be collected at each site is 1% of lower 90% confidence limit of the population in the size range of 81-120 mm SL estimated for that site. The maximum number of females that can be collected is 50% of the total number of abalone calculated.

The abalone must be collected within the surveyed sites only.

The proponent must apply for and receive a transplant licence (Licence to Import/Transfer Live Fish Into or Within the Province of British Columbia) from the Fed.-B.C. Prov. Introductions and Transfers Committee, prior to transplanting broodstock from the wild to a hatchery facility.

All collections are to be completed within a year, sooner if possible, of the transect surveys.

Collection should be 2-3 months before abalone are ready to spawn (late winter-early spring) to allow time for conditioning of the abalone for better egg and sperm yield.

Underwater collection

Only mature male and female abalone in the 81-120 mm shell length (SL) size range are to be removed. The number of abalone permitted will be determined by the transect survey(s) as described above. Wild abalone are collected by hand without the use of any sharp objects. An appendage of a sunflower starfish (*Pycnopodia helianthoides*) can be used to help remove an abalone gently off a rock. To avoid taking several abalone from potentially reproductive aggregations, divers count 9 abalone within the 80-120 mm SL size range and take the 10^{th} for broodstock.

If abalone have to be returned (e.g. too many were collected), the animals must be returned directly to the substrate by divers to minimize their initial vulnerability to predators.

Transport and arrival at the facility

Ideally, the abalone should be kept in a tank with circulating sea water during transport to the hatchery/aquaculture facility. The temperature of the water should be maintained at low temperatures (<10^{o}C).

Upon arrival at the holding facility, each abalone is tagged and a DNA sample is taken. The shell length and sex of each abalone collected as well as the tag number and DNA sample number are recorded (for an example a filled data sheet, see Fig. 5 in Appendix B). The records and the DNA samples must sent to DFO Stock Assessment.

Tagging

Each abalone collected for broodstock must be tagged. This will provide the means to follow the progress of each individual in the hatchery/aquaculture facility and when the animals are returned to the wild.

Numbered tags will be supplied by DFO Stock Assessment. The numbered tags are bonded to the shell with "Z-spar splash zone" epoxy. This 2 parts epoxy can be purchased at local marine hardware store. The epoxy requires mixing prior to application and working time is 20-30 minutes.

Premix a small amount of epoxy (30-50 ml). Work quickly to minimize the time that each abalone is exposed to air. Using a small power tool with a grinding bit, remove the sponge and coralline algae from a small area near the spiral (see diagram in Appendix E). Dry off and clean the cleared area with an air nozzle. (An air nozzle attachment mounted to a compressor or scuba tank works well.) A clean, dry shell will provide better adhesion of the glue over the long term. Apply the glue with a spatula and embed the tag with gloved hands. Ensure the tag is held firmly in place. The tagged abalone can be placed back into seawater immediately. Water flow should be increased for the first few hours to thoroughly flush out noxious chemicals that may be given off by the hardening epoxy. If tags fall off in the first 24 hours when the glue is still hardening, recover the tag and reapply.

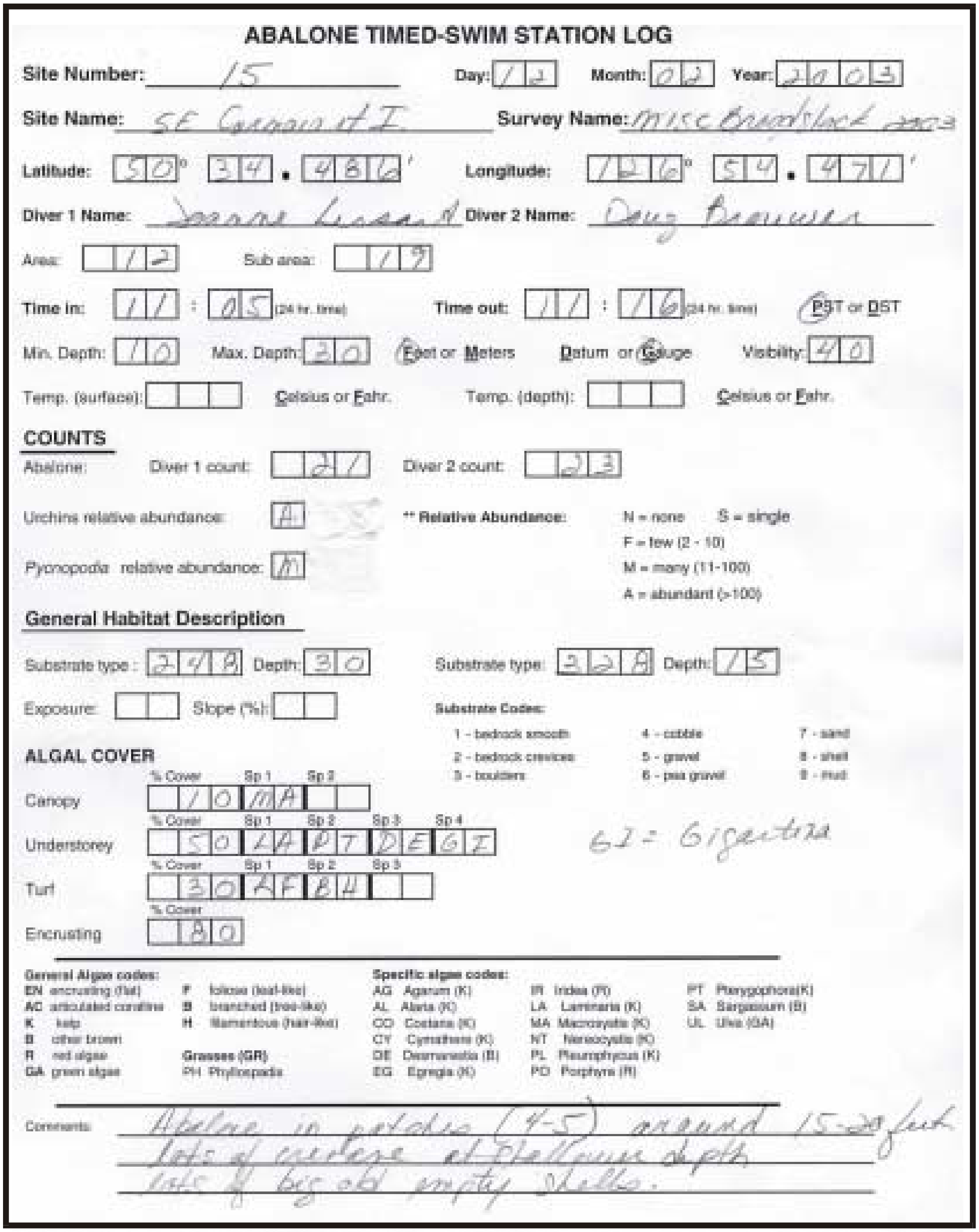
DNA sample

The DNA sample can be taken at the same time as the tagging is done. From each abalone, take a small clip of epipodial tissue (see Fig. 3 in Appendix D). Place each sample in 1.5 ml eppendorf tubes with screw caps filled with 70%, or higher, ethanol. **DO NOT** substitute another alcohol. These samples can be stored and shipped at ambient temperature. The individual tubes need to be labelled to match with shell length measurements and tag numbers. Label each box with the collection site info (site name or latitude and longitude, date, species).

Return of broodstock to the wild

Broodstock must be returned with tags intact (for future monitoring of survival) to the original collection site, under the supervision of a DFO-certified biological monitor. Abalone must be returned directly to the substrate by divers to minimize their initial vulnerability to predators. Consideration is not given for "exchange" of broodstock, *i.e.* returning a number of abalone and collecting the equivalent number of new broodstock. The proponent must apply for and receive a transplant licence (Licence to Import/Transfer Live Fish Into or Within the Province of British Columbia) from the Fed.-B.C. Prov. Introductions and Transfers Committee, prior to transplanting broodstock from a hatchery facility to the original site of collection. Disease testing of the transplanted abalone may be required by the transplant committee.

Appendix B: Examples of filled data sheets



ABALONE TIMED-SWIM STATION LOG

Site Number: 15   Day: 12   Month: 02   Year: 2003

Site Name: SE Gordon? I   Survey Name: misc Broodstock 2003

Latitude: 50° 34 . 486′   Longitude: 126° 54 . 471′

Diver 1 Name: Joanne Lessard   Diver 2 Name: Doug Brouwer

Area: 12   Sub area: 19

Time in: 11 : 05 (24 hr. time)   Time out: 11 : 16 (24 hr. time)   PST or DST

Min. Depth: 10   Max. Depth: 20   Feet or Meters   Datum or Gauge   Visibility: 40

Temp. (surface): ___ Celsius or Fahr.   Temp. (depth): ___ Celsius or Fahr.

COUNTS

Abalone: Diver 1 count: 21   Diver 2 count: 23

Urchins relative abundance: A   ** Relative Abundance: N = none   S = single

Pycnopodia relative abundance: M   F = few (2 - 10)   M = many (11-100)   A = abundant (>100)

General Habitat Description

Substrate type: 248   Depth: 30   Substrate type: 228   Depth: 15

Exposure: ___   Slope (%): ___

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

ALGAL COVER

Canopy: % Cover 10, Sp 1 MA, Sp 2 —

Understorey: % Cover 50, Sp 1 LA, Sp 2 PT, Sp 3 DE, Sp 4 GI   GI = Gigartina

Turf: % Cover 30, Sp 1 AF, Sp 2 BH, Sp 3 —

Encrusting: % Cover 80

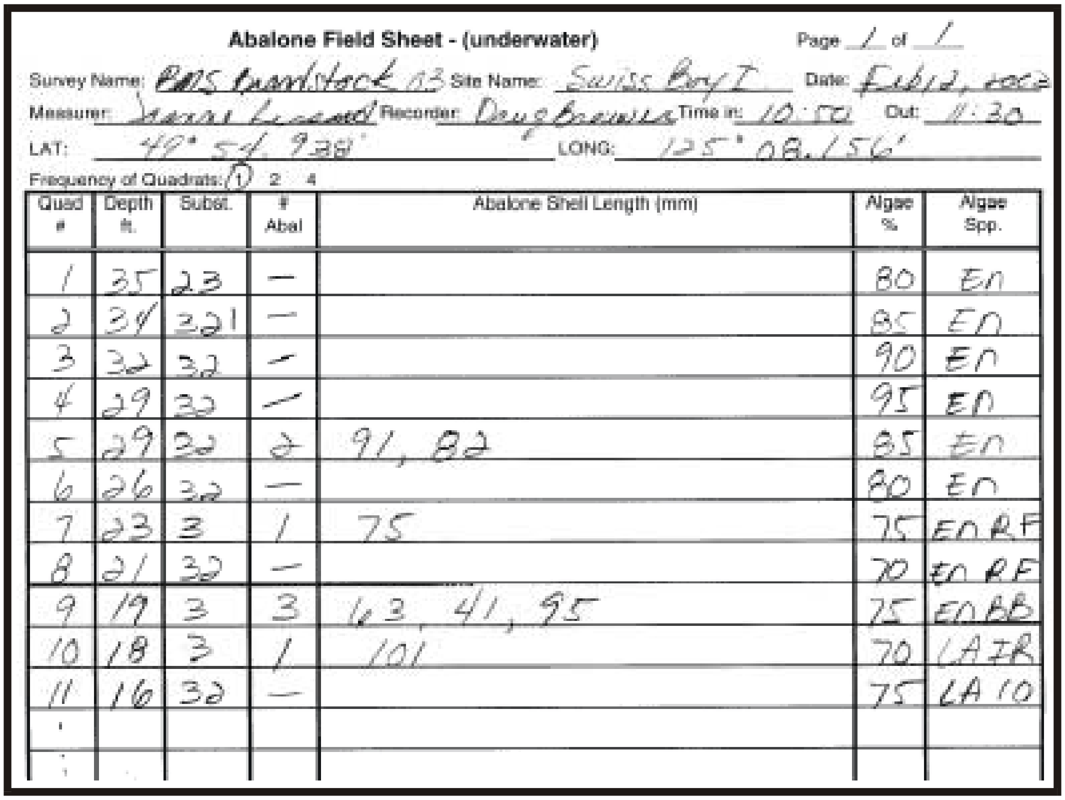
General Algae codes:
EN encrusting (flat)
AC articulated coralline
K kelp
B other brown
R red algae
GA green algae
F foliose (leaf-like)
B branched (tree-like)
H filamentous (hair-like)

Grasses (GR)
PH Phyllospadix

Specific algae codes:
AG Agarum (K)
AL Alaria (K)
CO Costaria (K)
CY Cymathere (K)
DE Desmarestia (B)
EG Egregia (K)
IR Iridea (R)
LA Laminaria (K)
MA Macrocystis (K)
NT Nereocystis (K)
PL Pleurophycus (K)
PO Porphyra (R)
PT Pterygophora (K)
SA Sargassum (B)
UL Ulva (GA)

Comments: Abalone in patches (4-5) around 15-20 feet
lots of urchins at shallower depth
lots of big old empty shells.

Figure 1. Example of a filled timed-swim survey sheet.

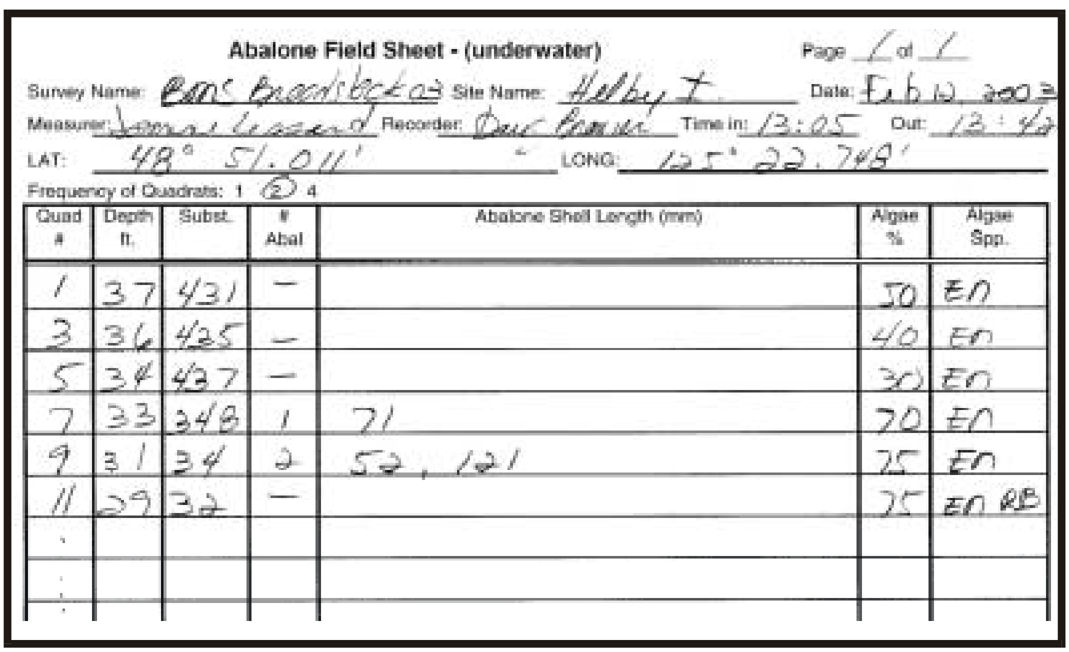


Abalone Field Sheet - (underwater)   Page 1 of 1

Survey Name: BMS broodstock 03 Site Name: Swiss Boy I Date: Feb 12, 2003
Measurer: Joanne Lessard Recorder: Doug Brouwer Time in: 10:50 Out: 11:30
LAT: 48° 54.938' LONG: 125° 08.156'
Frequency of Quadrats: (1) 2 4

Quad #	Depth ft.	Subst.	# Abal	Abalone Shell Length (mm)	Algae %	Algae Spp.
1	35	23	—		80	En
2	34	321	—		85	En
3	32	32	—		90	En
4	29	32	—		95	En
5	29	32	2	91, 82	85	En
6	26	32	—		80	En
7	23	3	1	75	75	En RF
8	21	32	—		70	En RF
9	19	3	3	63, 41, 95	75	En BB
10	18	3	1	101	70	LA ZR
11	16	32	—		75	LA 10

Figure 2. Example of a filled underwater sheet for a transect 20 m or less where every quadrat is sampled (frequency = 1).

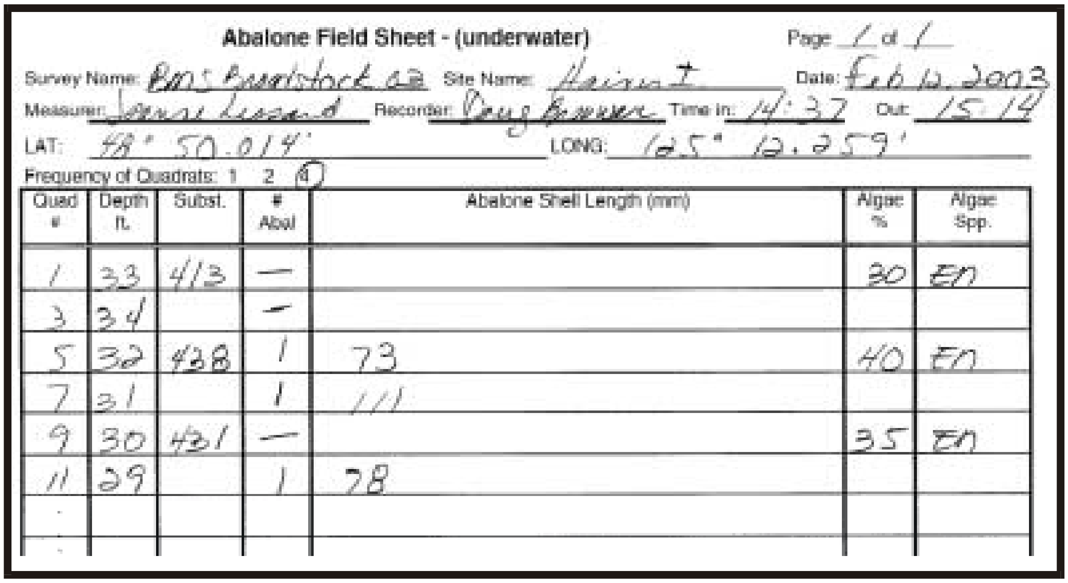


Abalone Field Sheet - (underwater)   Page 1 of 1

Survey Name: BMS broodstock 03 Site Name: Helby I Date: Feb 12, 2003
Measurer: Joanne Lessard Recorder: Doug Brouwer Time in: 13:05 Out: 13:42
LAT: 48° 51.011' LONG: 125° 22.748'
Frequency of Quadrats: 1 (2) 4

Quad #	Depth ft.	Subst.	# Abal	Abalone Shell Length (mm)	Algae %	Algae Spp.
1	37	431	—		50	En
3	36	435	—		40	En
5	34	437	—		30	En
7	33	348	1	71	70	En
9	31	34	2	53, 121	75	En
11	29	32	—		75	En RB

Figure 3. Example of a filled underwater sheet for a transect longer than 20 m and less than 60 m where every second quadrat is sampled (frequency = 2).



Abalone Field Sheet - (underwater)

Page 1 of 1

Survey Name: BMS Broodstock 03 Site Name: Hanson I. Date: Feb 12, 2003

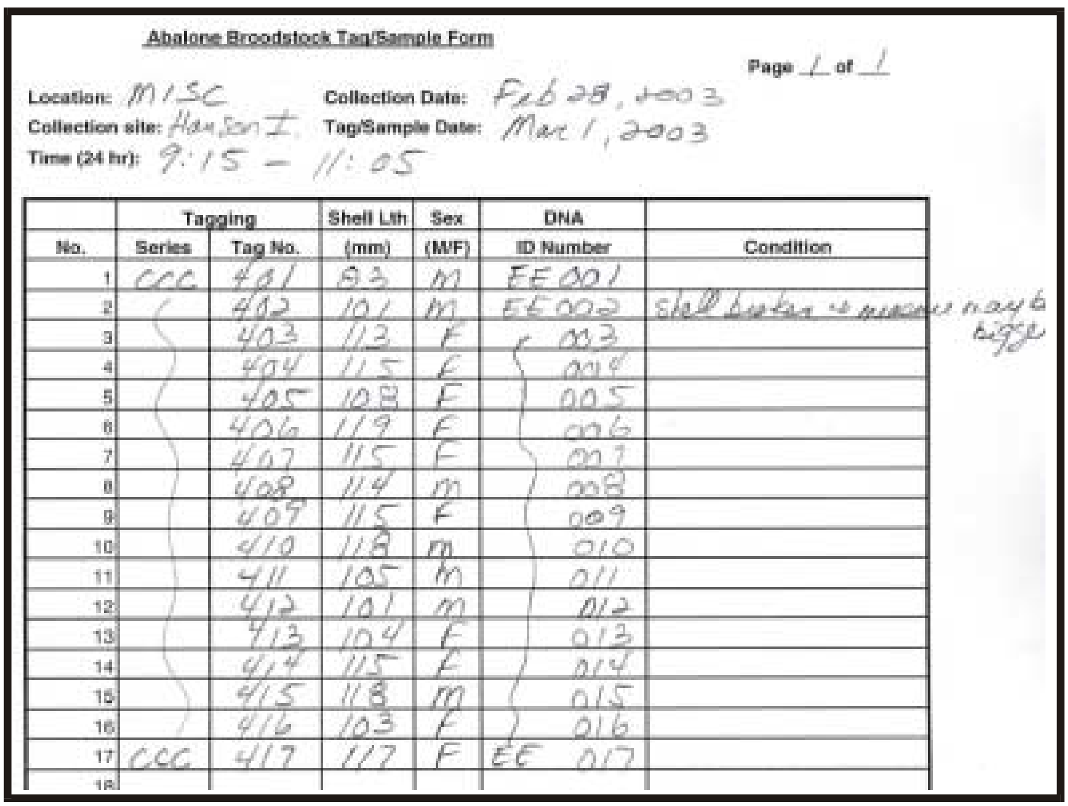
Measurer: [illegible] Recorder: Doug Brouwer Time in: 14:37 Out: 15:14

LAT: 48° 50.014' LONG: 125° 12.259'

Frequency of Quadrats: 1 2 4

Quad #	Depth ft.	Subst.	# Abal	Abalone Shell Length (mm)	Algae %	Algae Spp.
1	33	4/3	—		30	En
3	34		—			
5	32	438	1	73	40	En
7	31		1	111		
9	30	431	—		35	En
11	29		1	78		
.						
.						

Figure 4. Example of a filled underwater sheet for a transect longer than 60 m where every second quadrat is sampled for abalone and depth and every fourth completely (frequency = 4).



Abalone Broodstock Tag/Sample Form

Page 1 of 1

Location: MISC Collection Date: Feb 28, 2003

Collection site: Hanson I. Tag/Sample Date: Mar 1, 2003

Time (24 hr): 9:15 – 11:05

No.	Tagging Series	Tagging Tag No.	Shell Lth (mm)	Sex (M/F)	DNA ID Number	Condition
1	CCC	401	83	M	EE001	
2		402	101	M	EE002	shell broken - measure may be bigger
3		403	113	F	003	
4		404	115	F	004	
5		405	108	F	005	
6		406	119	F	006	
7		407	115	F	007	
8		408	114	M	008	
9		409	115	F	009	
10		410	118	M	010	
11		411	105	M	011	
12		412	101	M	012	
13		413	104	F	013	
14		414	115	F	014	
15		415	118	M	015	
16		416	103	F	016	
17	CCC	417	117	F	EE 017	
18						

Figure 5. Example of a filled tagging and DNA sample data sheet.

Appendix C: Abalone Dive Survey 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

General Algal Codes

K	kelp
B	other brown
R	red algae
GA	green algae
F	foliose (leaf-like)
B	branched (tree-like)
H	filamentous

Red Algae

PO	Pophyra (R)
IR	Iridaea (R)
GI	Gigartina (R)
AC	Articulated Coralline
EN	Encrusting

Green Algae

UL	Ulva (GA)

Brown Algae

MA	Macrocystis (K)
NT	Nereocyctis (K)
LA	Laminaria (K)
CO	Costaria (K)
AG	Agarum (K)
EG	Egregia (K)
CY	Cymathere (K)
AL	Alaria (K)
PL	Pleurophycus (K)
PT	Pterygophora (K)
DM	Desmarestia (K)
FU	Fucus (B)
SA	Sargassum (B)

Other Codes

GR	unknown sea grass
ZO	Zostera (GR)
PH	Phyllospadix (GR)

Appendix D: Abalone Diagram

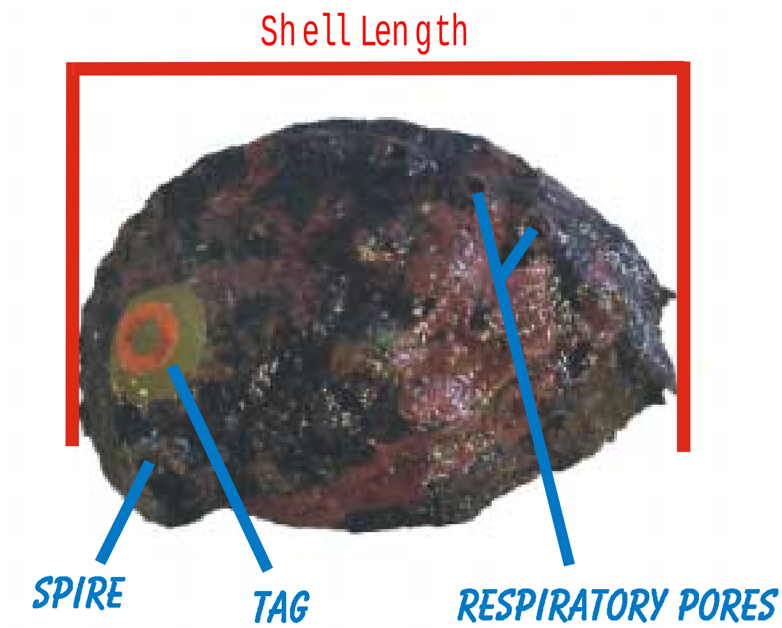


Figure 1. Dorsal view of a Northern abalone showing maximum shell length for measurement, tag placement location and some morphological features.

Figure 2. Photo showing proper measurement technique.

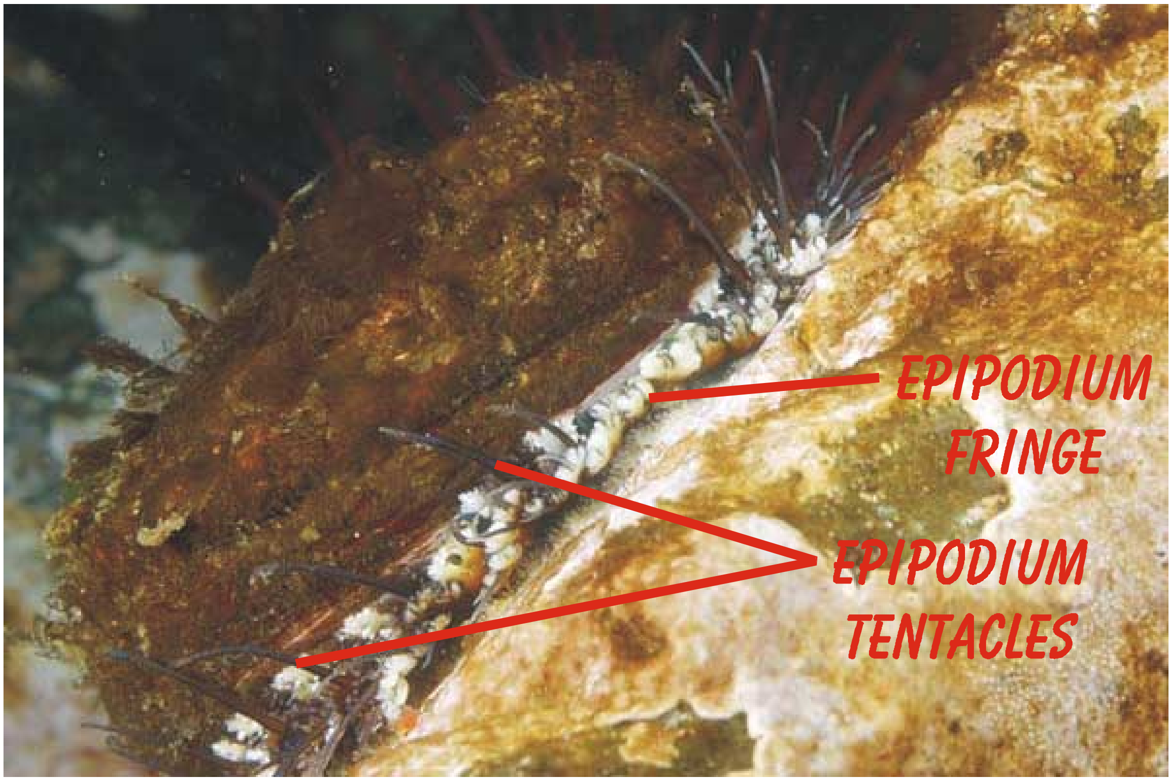


Figure 3. Photo showing the epipodium tentacles and fringe for DNA sample clipping. (photo: Copyright Keith and Jon, http://www.seaotter.com/marine-life.html)

PSARC INVERTEBRATE SUBCOMMITTEE

Request for Working Paper

Date Submitted: Feb. 28,2002 (Revised Mar. 7)

Individual or group requesting advice:

(Fisheries Manager/Biologist, Science, SWG, PSARC, Industry, Other stakeholder etc.)

Fisheries Managers

Proposed PSARC Presentation Date:

June, 2002

Subject of Paper (title if developed):

Abalone survey protocols and the rationale and protocols for the removal (and return) of allowable numbers of Northern Abalone, from areas in B.C. for use as broodstock in aquaculture

Stock Assessment Lead Author: Alan Campbell, B.Lucas, D. Brouwer + statistician

Fisheries Management Author/Reviewer: R. Harbo and L. Convey

Rationale for request:

(What is the issue, what will it address, importance, etc.)

A draft paper on this topic was prepared for the Nov. 1999 PSARC Shellfish Subcommittee Meeting.

Abalone surveys (5) have been conducted to date have produced results that should be reviewed. Sampling methods have been adapted from earlier surveys and should be reviewed. For example, in one survey, less than 1m^2/ha(10,000m^2) was sampled and the CI were “tight” because of the low densities. From 131 abalone counted in 460 m^2, estimates of 1,786,000 abalone were made for the surveyed area of 627 ha. Sampling of less than 1m2/ha in an abalone survey is significantly less than in other dive surveys (eg. geoduck surveys sample >50m^2/ha).

Criteria for collection presented are 1% of the lower CI of 90-110mm SL emergent abalone, or 30 /site. The options at this site would be 30 abalone, not 4,320 abalone at 1%.

The survey methodologies, survey results and any protocols for removals will be challenged by a number of stakeholders, considering the “threatened” status of abalone stocks.

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

(To be developed by initiator)

1. **What is the appropriate survey methodology for abalone surveys**. Considering the low densities of abalone, what is an appropriate sampling intensity (m^2 sampled / ha of abalone site?). The number of transects per km of shoreline should be re-examined and a methodology adapted that considers the number of quadrats/ha as well.
2. **What is the max. number of abalone that should be collected at any given site or “local abalone population”** : there needs to some definition of the “area” of a site and/or “local population”; eg. min.# abalone to be collected/ha or 10 ha (or ?) to make the application of the protocol reasonable. There should be some reference for how the number 30 individual abalone from a local abalone population was determined.
3. **What is the appropriate time that a survey is valid**? Initial recommendations are 2-3 months. This has not proved to be practical, and removals have been proposed in March ,2002 based on surveys in October, 1999.
4. **What are the appropriate size ranges of abalone to be removed for broodstock? This was based on egg per recruit analyses by Campbell (1997).**
5. **Removal of abalone in high densities, local patches of >4m2 should be avoided.** If these densities are encountered, how great an area (ha) should be left unharvested at a given site?
6. **How long should broodstock be held in an aquaculture facility** ? the initial recommendation was no longer than six months or a year (?). **How many times should the broodstock be conditioned and spawned**, before their return?

Objective of Working Paper:

(To be developed by FM & StAD for internal papers)

To protect endangered abalone stocks. To consider removals of abalone for broodstock for “captive breeding” programs and to consider broodstock for the development of commercial aquaculture.

Stakeholders Affected:

All stakeholders, considering there is a total closure to any harvest of abalone and they are listed as “threatened”. Abalone are culturally important to First Nations. There is great interest in abalone from recreational harvesters (and potentially commercial harvesters), and prospective aquaculturists.

How Advice May Impact the Development of a Fishing Plan:

Advice will determine if abalone should be collected for broodstock for captive breeding, and if surplus abalone re available for broodstock collection for commercial aquaculture or other harvest (eg. First Nations food, social, ceremonial).

Timing *Issues Related to When Advice is Necessary*

Some surveys and broodstock collections have taken place in 1999, 2000 and 2001. There is a need to review these activities and review the rationale and protocols for future removals of abalone.