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Do predators, handling stress or field acclimation periods influence the survivorship of hatchery-reared abalone Haliotis kamtschatkana *outplanted into natural habitats?*

S. CHRISTINE HANSEN[a] and LOUIS A. GOSSELIN[a,b,*]
[a]*Department of Biological Sciences, Thompson Rivers University, Kamloops, B.C. V2C 0C8, Canada*
[b]*Department of Biology, University of Victoria, Victoria, B.C. V8W 3N3, Canada*

ABSTRACT

1. Northern abalone (*Haliotis kamtschatkana*) in British Columbia, Canada, are listed as endangered and are protected from fishing, yet their populations continue to decline. It is suspected that supplementation of wild populations with hatchery-reared abalone will be necessary for the recovery of this species. This study examines the magnitude, timing, and causes of post-outplanting mortality of hatchery-reared late-juvenile northern abalone.

2. Abalone survivorship declined precipitously following outplanting, with 83% of abalone surviving 24 h after release and only 34% surviving 2 weeks in the wild.

3. Handling, tagging, and temperature variations experienced during the outplanting procedure did not cause mortality. The majority of the abalone mortality in this study was attributable to predators. Additional factors accounted for only 1–2% mortality over 7 d.

4. A 1-week acclimatization period within predator exclosures did not improve subsequent survival of outplants.

5. These results demonstrate that the ouplanting of hatchery-reared abalone as a method of restoring wild populations of this endangered species is primarily constrained by high mortality during the first few days after outplanting, and that almost all of this early mortality is caused by predation. Predation mortality will therefore have to be overcome if outplanting of hatchery-reared juvenile abalone is to be an effective restoration strategy.

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KEY WORDS: ocean; subtidal; coastal; endangered species; predation; restoration; benthos; invertebrates; aquaculture; fishing

INTRODUCTION

Overfishing, combined with ineffective management, has driven marine fisheries into a crisis across the globe (Pauly *et al.*, 1998; Rose and Kulka, 1999). In some cases entire fisheries have been closed, with no subsequent recovery of the exploited species. A recent example involves the northern abalone, *Haliotis kamtschatkana*, the only abalone species found in Canada. This species once supported commercial, recreational, and First Nations fisheries in British Columbia, Canada; however, following concern over declining populations, all three of these fisheries were closed in 1990 (Lessard *et al.*, 2007). Over the following years population declines continued such that northern abalone were listed as 'threatened' by the Committee on the Status of Endangered Wildlife in Canada in 1999,

*Correspondence to: L. A. Gosselin, Department of Biological Sciences, Thompson Rivers University, 900 McGill Road, Kamloops B.C., V2C 0C8, Canada. Email: lgosselin@tru.ca

and as 'endangered' in 2009 (COSEWIC, 2009). Given the failure of this species to recover on its own over the two decades since the fishery closure, it has been suggested that restocking wild populations with hatchery-reared abalone may be one of the only options for rebuilding wild populations to self-sustaining densities (Bouma, 2007; Lessard *et al*., 2007; Straus and Friedman, 2009). Previous outplanting experiments using hatchery-reared abalone of other species, however, achieved highly variable levels of success with post-seeding abalone survival ranging from 1–80% (reviewed in McCormick *et al*., 1994). A recent study of *H. kamtschatkana* outplanted in British Columbia demonstrates that survival is extremely low several years after outplanting, yet still has the potential to augment low density populations (Read *et al*., 2012). The outplanting of hatchery-reared abalone into wild populations can be an effective restoration strategy only if we adequately understand the magnitude and timing of post-outplanting mortality as well as the factors responsible for this mortality; such knowledge would then serve as the basis for developing outplanting procedures that minimize post-outplanting mortality.

Currently, the factors responsible for the high mortality of hatchery-reared abalone outplanted to natural habitats are unknown. Several potential factors, however, have been proposed. Predators, such as crabs, seastars, and octopuses, are known to kill abalone and have been suggested as major causes of mortality of outplanted *H. rufescens* (Tegner and Butler, 1985; Rogers-Bennett and Pearse, 1998) and *H. discus discus* (Kojima, 1981). In *H. kamtschatkana*, when juveniles grow larger than 13 mm shell length (SL) they become too large to be killed by two small-bodied crab species (*Scyra acutifrons* and *Lophopanopeus bellus*) and by most small individuals of the two other important predator species, the crab *Cancer productus* and the seastar *Pycnopodia helianthoides* (Griffiths and Gosselin, 2008). Griffiths and Gosselin therefore proposed that *H. kamtschatkana* should be outplanted at sizes larger than 13 mm SL to ensure they have outgrown a large proportion of their predators. Species likely to prey on large juvenile and adult *H. kamtschatkana* include *C. productus* and *P. helianthoides*, as well as *Octopus dofleini, Enhydra lutris, Scorpaenichthys marmoratus* and *Anarrhichthys ocellatus* (Sloan and Breen, 1988).

In addition to predation, the stress incurred from the outplanting process itself, in particular from the tagging, handling, and introduction to a new environment, is often thought to cause substantial mortality of outplanted abalone (Schiel, 1993; McCormick *et al*., 1994; Sweijd *et al*., 1998; Shepherd *et al*., 2000; Tegner, 2000; Dixon *et al*., 2006; Kiyomoto, 2007). Such effects of the individual procedures, however, have not been demonstrated and thus remain speculative. The goals of this study were therefore to: (1) document the chronological sequence of short-term post-outplanting survivorship in hatchery-reared *H. kamtschatkana;* (2) determine the role of five sets of factors as causes of post-outplanting mortality: tagging, handling, thermal stress during outplanting, predators, and natural causes other than predation; and (3) determine whether a period of acclimation within predator exclusion cages in the field can improve the survivorship of outplanted *H. kamtschatkana*.

METHODS

This project was conducted in 2009 at the Bamfield Marine Sciences Centre and at a field site located at the south-west end of Fleming Island in Barkley Sound, on the west coast of Vancouver Island, British Columbia, Canada. As part of a broader project aiming to enhance the survivorship of outplanted *Haliotis kamtschatkana*, and ultimately restore populations to self-sustaining densities, the present study examined survivorship and causes of mortality in an experiment involving 1680 hatchery-raised abalone. Of these, 560 were destined for tagging, while the remainder were untagged. Tagging involved affixing numbered bee tags (Queen Marking Kits from The Bee Works, ON, Canada) to the shell near the spire with Superglue®. The abalone used in this study ranged in size from 4.23 to 6.46 cm shell length (SL).

Abalone were returned to hatchery tanks after handling and tagging and were fed *ad libitum* with the kelp *Nereocystis leutkeana* for 1 week before outplanting. The day before outplanting, abalone were placed into half-sections of PVC tubes (30 cm length × 15–20 cm diameter), which were then paired up to form a complete tube containing 20 abalone each. A few blades of *N. leutkeana* were placed in each tube and then the ends were covered with Vexar® mesh allowing water flow-through but keeping the abalone within. Tubes containing abalone were held in hatchery tanks for 24 h before outplanting to allow the abalone to attach and acclimate. These PVC outplanting modules were used to minimize the stress experienced by abalone

during the outplanting process, as they allow an abalone to adhere undisturbed to the inner surfaces of the tube throughout the outplanting process, avoiding direct handling of the abalone.

The experiment involved the following six treatments: (1) tagged abalone outplanted directly onto the substratum and allowed to immediately begin crawling out of the tubes and into the surrounding habitat; (2) tagged abalone enclosed for 1 week in predator exclusion cages that were suspended 1 m above the substratum; (3) tagged abalone enclosed for 1 week in predator exclusion cages attached directly to the substratum (grounded); (4) tagged abalone handled in the same way as in treatments 1, 2 and 3, including transportation out and down to the outplanting locations by the scuba divers, but then returned to the surface and then back to hatchery tanks (not outplanted); (5) untagged abalone handled in the same way as in treatment 4; and (6) untagged abalone that were left in hatchery tanks for the duration of the experiment (not handled). Predator exclusion cages (Figure 1) were $61 \times 30.5 \times 30.5$ cm, lined with 0.5 cm mesh. One week after outplanting, all abalone in treatments 2 and 3, which were still in their outplanting tubes within the cages, were released by placing the tubes on the substratum at the base of the cages and weighing the tubes down with rocks, thus allowing the abalone to disperse. Treatments 4, 5, and 6 served as controls for handling and tagging effects.

Abalone were outplanted to the Fleming Island site, where abalone habitat extended more than 70 m along the shoreline at depths of 0–12 m (see Lessard and Campbell, 2007 for a description of optimal northern abalone habitat). A lead line was placed at 9 m depth parallel to the shore, along a 70 m length of the habitat; the line was affixed to cement blocks at either end and further weighed down at intervals by small boulders. The experiment involved seven replicate locations positioned at 10 m intervals along the line; at each location, one suspended and one grounded predator exclusion cage (Figure 1) were attached, such that the same outplanting locations were used for treatments 1, 2 and 3. The numbered tags allowed abalone from these three treatments to be distinguished during the post-outplanting surveys. Overall, the experimental design consisted of six treatments $\times$ seven replicates per treatment $\times$ 20 abalone per replicate in treatments 1–5. Given that treatment 6 consisted of unhandled, untagged abalone in hatchery tanks, the numbers of abalone were dependent on the stocking practices of the hatchery. As such, the average number of abalone per replicate in this treatment was 140 ± 3 individuals.

At each outplanting location, searches for marked abalone were conducted on days 1, 3, 7, 10 and 14 after outplanting using circular swath surveys; these surveys consisted of explorations of 5 m radius circular areas centred on each outplant location. The 5 m radius area used for these surveys was

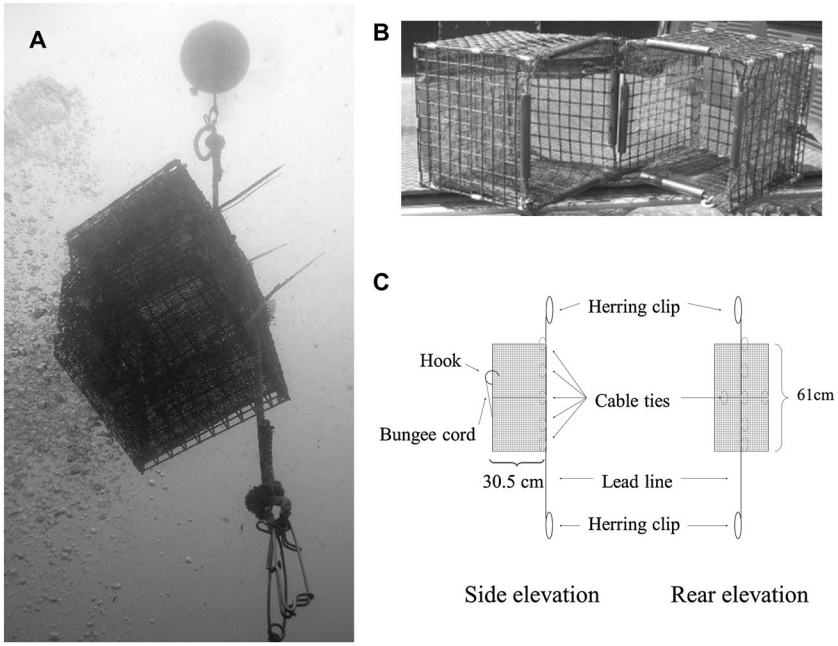

Figure 1. Predator exclusion cages for abalone outplanting. (A) Suspended cage deployed in the field; (B) opened cage, lined with Vexar® of 0.5 cm mesh size; (C) design and attachment sites of suspended cages.

selected based on a pilot study showing that over 99% of outplanted *H. kamtschatkana* remain within 3 m of the outplanting site over the following 2 week period (Hansen, 2011). Abalone in the predator exclusion cages (treatments 2 and 3) and in the hatchery (treatments 4, 5 and 6) were also examined on days 1, 3 and 7 to determine the number of surviving abalone in those treatments.

The temperature conditions experienced by abalone during outplanting were recorded using eight iButton® temperature loggers (Maxim Integrated Products, Inc., CA, USA) randomly assigned to eight replicate tubes of treatments 4 and 5, and set to record at 1 min intervals. Temperature loggers were also placed in hatchery tanks for 2 days before outplanting to determine the baseline temperature.

The survivorship of abalone outplanted to the field (treatments 1, 2 and 3) was estimated by applying the Jolly–Seber method to resightings of tagged abalone in the post-outplanting surveys. Resighting information was also transcribed into vectors such that the Barker model in program MARK 6.0 could be employed to estimate recapture probability for the three outplanted treatments.

Survivorship was compared among treatments using a randomized complete block ANOVA; the bivariate response variable was survivorship, the predictor was outplanting treatment (fixed; six treatment levels), and the blocking factor was location (random; seven blocks). When significant, an ANOVA was followed up with a Tukey HSD post-hoc multiple comparisons test to compare among pairs of treatments. A first analysis was carried out in this way to determine the role of individual mortality factors by comparing survivorship to day 7 among the six treatments. A second analysis was then carried out to clarify the effectiveness of a 1 week caged field acclimation period in reducing vulnerability to predators once transferred to the substrate. The second analysis therefore involved a randomized complete block ANOVA comparing survivorship in treatment 1 on day 7 with survivorship in treatments 2 and 3 on day 14 of the experiment, the latter corresponding to 7 days after those abalone were released from their cages onto the substratum.

The extent to which the temperatures experienced by abalone during the outplanting process deviated from hatchery water temperature was estimated by calculating the differential, in degree minutes (DM), between hatchery and outplanting tube temperatures, as follows:

$$DM = \sum (To_1 - Th) + \ldots + (To_n - Th)$$

where Th is the average seawater temperature in hatchery tanks during the 2 days before outplanting, and To_1 to To_n are the temperatures in the outplanting tube measured at 1 min intervals from the time the abalone were removed from the hatchery tanks on outplanting day (To_1) to the time during the outplanting process when the abalone were returned to the hatchery and temperatures settled back to Th.

RESULTS

Abalone outplanted directly to the substratum (treatment 1) experienced a rapid drop in survivorship over the 2 week period following outplanting (Figure 2). A large drop in survivorship of $16.6 \pm 5.3\%$ (mean +/− SE) occurred in the first day. In the following days, survivorship continued to decline, dropping to only $33.8 \pm 14.3\%$ by day 14.

There were significant differences among the six treatments in abalone survivorship up to day 7 (ANOVA: $F_{5,30} = 18.808$, $P < 0.001$), with survivorship in treatment 1 being significantly lower than in the other five treatments (Figure 3). Very little mortality occurred in treatments 2–6. All abalone outplanted into cages, whether suspended or grounded (treatments 2 and 3), survived the first 3 days in the field; the first dead abalone in these two treatments were encountered on day 7, and even then only six individuals had died out of 280 abalone in these two treatments. Survivorship was not significantly affected by tagging, as almost all abalone in treatments 4 (tagged) and 5 (untagged) survived the 7 day monitoring period (Figure 3). There was also no significant difference in survivorship between treatments 5 (brought to the field then

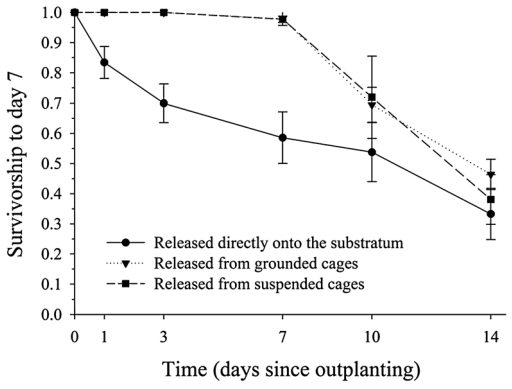

Figure 2. Survivorship of hatchery-reared *Haliotis kamtschatkana* outplanted directly onto the substratum (treatment 1), into grounded cages (treatment 2), or into suspended cages (treatment 3), over the 14 day period following outplanting. Error bars represent SE; n = 7.

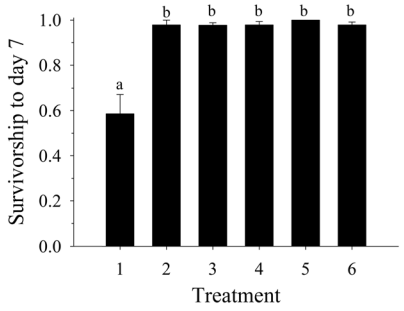

Figure 3. Survivorship of treatment and control abalone to day 7 of the experiment. Abalone were outplanted either directly on the substratum (no cage, treatment 1), into suspended cages (treatment 2), or into grounded cages (treatment 3). Control treatments involved abalone that were either tagged, brought to the field and returned to laboratory tanks (treatment 4); not tagged, brought to the field and returned to the laboratory (treatment 5), or not tagged or handled, left undisturbed in the hatchery (treatment 6). Error bars represent SE; n = 7. Values with the same letter are not significantly different, as determined by Tukey HSD tests.

returned to hatchery tanks within a few hours) and 6 (left in hatchery tanks, not handled), indicating that handling during the outplanting process was not a direct cause of mortality.

Seawater temperature in the hatchery tanks averaged 10.88 ± 0.01°C (±SE) during the 2 days before outplanting. The cumulative DM, a measure of temperature variation experienced by abalone during the outplanting process relative to hatchery temperatures, averaged 161.23 ± 60.73°C (±SE; n = 8 replicate tubes). The lowest DM recorded in an outplanting tube was 2.19°C, whereas the highest was 550.14°C. This disparity of DM values occurred because the replicate tubes were held on the boat for different periods of time before they could be brought down to the sea bottom, one at a time, by the scuba divers. Thus, abalone in tubes outplanted at the end of the outplanting process reached higher DM values than the first abalone to be brought down to the bottom. Despite the disparity in DM among replicates of treatments 4 and 5 (brought to the field then returned to hatchery tanks within a few hours), survivorship in these treatments during the 7 day monitoring period was 97% and 100%, respectively, and these values were not significantly different from the survivorship of abalone in treatment 6, which were left undisturbed in hatchery tanks (Figure 3). Hence, outplanting temperatures and a brief exposure to the natural environment did not influence survivorship. Similarly, exposure to the natural environment for 7 days within the protection of cages (treatments 2 and 3) did not result in significantly lower survivorship than for abalone left in the hatchery (treatment 6).

There was no significant difference in survivorship between the two caged treatments (2 and 3) during the enclosed period (day 7, Figure 3) or after release onto the substratum (Figure 2), indicating that the position of the cages had no influence on survivorship. Predator exclusion cages did substantially improve abalone survivorship, with almost no mortality while abalone were held within the cages. Predators therefore do appear to have had a substantial and early impact on the survivorship of outplanted abalone. On day 7 of the experiment, the survivorship of abalone released directly onto the substrate (treatment 1), as estimated by the Jolly–Seber method, was 57.9 ± 7.1%, compared with 97.9–100.0% in the controls (treatments 4, 5, 6) and 97.7–97.9% in the predator exclusion cages (treatments 2 and 3) during that same time period (Figure 3). In addition, when caged abalone in treatments 2 and 3 were transferred from the cages to the nearby substratum on day 7, their survivorship over the following 7 days dropped below 50%, such that by day 14 of the experiment survivorship was no longer significantly different among treatments 1, 2 and 3 (Figure 2; ANOVA: $F_{2,12} = 0.739$, $P = 0.498$), nor was survivorship during the 7 days after release from the cages significantly different from that of abalone in treatment 1 during the first 7 days on the substratum (ANOVA: $F_{2,\ 12} = 1.742$, $P = 0.217$) indicating that the 1 week acclimation does not alter the outcome of exposure to predators (i.e. high mortality). However, this may have been partially due to reduced recapture probabilities of abalone released from the cages, as determined using the Barker model. Recapture probabilities estimate the probability that abalone that are alive and within the survey area at the time of the survey are actually recaptured during the survey. These values are different from survivorship estimates in that the latter estimate the probability that abalone are alive regardless of whether they are in the survey area or not at the time of the survey. Recapture probabilities therefore inform us of our detection abilities for outplanted abalone and thus to some extent whether abalone are occupying cryptic spaces. This is due to the fact that emergent abalone are relatively easy to locate, whereas cryptic abalone occasionally occupy crevices or spaces that are inaccessible to survey divers. If abalone released from cages and those released directly onto the substrate were released in different areas one might conclude that the two areas differed in terms of available cryptic habitat. However, all treatments were released into the same

areas. Thus the reduced recapture probabilities of abalone released from cages reveals that these abalone were harder to find (and probably adopting more cryptic behaviours) during surveys than abalone planted directly onto the substrate (Table 1).

DISCUSSION

More than 65% of the hatchery-reared *Haliotis kamtschatkana* died within 2 weeks of being outplanted to the field (treatment 1), with 16.6% dying in the first day. This sharp decline in survivorship of abalone outplanted directly to the substratum was considerably more pronounced than would be expected for wild individuals of the same size in the same region. Notably, previous studies have shown the annual survival rate for 3–5 year old wild *H. kamtschatkana* in British Columbia to be 81.9% (Breen, 1980, 1986; Fournier and Breen, 1983; Sloan and Breen, 1988), which corresponds to 99.2% survivorship (or 0.8% mortality) over a 2 week period. Those 3–5 year old wild *H. kamtschatkana* were of a similar age and size range to the hatchery individuals outplanted in this study. The mortality of hatchery-raised abalone during the first 2 weeks in the wild (treatment 1 of the present study) was therefore almost two orders of magnitude higher than for wild abalone of comparable age and size. Other studies have also found discrepancies in the survival of wild and hatchery-raised abalone. For example, hatchery-raised *H. iris* juveniles experience 25% greater mortality after 5 weeks than their wild conspecifics (Schiel, 1992). The rapid decline in post-outplanting survivorship recorded in the present study is also consistent with reports for other abalone species. Notably, Schiel (1993) found that the greatest mortality for seeded *H. iris* occurred in the first few months following outplanting, while in a review of abalone outplanting, McCormick *et al.* (1994) stated that high mortality of abalone outplants often occurred within hours of their release. The success of outplanting as a restoration strategy, for *H. kamtschatkana* as well as for other abalone species, is therefore constrained primarily by mortality occurring very shortly after outplanting.

The present study specifically examined the effects of the outplanting procedure itself on abalone survivorship, and no such effects were detected: tagging, handling, and temperature stress during the procedure did not affect survivorship. This was a surprising finding, given that stress induced from tagging, handling, and introducing abalone to a new environment have been suggested as significant causes of abalone mortality, particularly with regards to immediate post-outplanting mortality of outplants (Tegner and Butler, 1985; Schiel, 1993; McCormick *et al.*, 1994; Sweijd *et al.*, 1998; Shepherd *et al.*, 2000; Tegner, 2000; Dixon *et al.*, 2006; Kiyomoto, 2007). The absence of detectable effects of outplanting procedures on survivorship in this present study may have resulted from the adoption of methods designed to minimize stress, such as the use of outplanting tubes that did not require that abalone be dislodged or directly handled during the outplanting process. The stress experienced by abalone during the tagging and outplanting procedures therefore appears to be insufficient to cause mortality, although the stress may have increased their vulnerability to predators (Olla *et al.*, 1998).

The identity and importance of non-predatory factors as causes of mortality in subtidal benthic marine invertebrates are poorly understood (Gosselin and Qian, 1997). Factors such as disease and parasites are known to cause mortality in both wild and cultured individuals of other abalone species and in aquaculture settings for *H. kamtschatkana* (Bower, 2000). Indeed, the protist parasite *Labyrinthuloides haliotidis* decimated young *H. kamtschatkana* at an aquaculture facility in BC

Table 1. Recapture probabilities (p) and associated standard errors of hatchery-reared abalone outplanted into the wild in three treatments over time. The treatments are: (1) outplanted directly onto the substrate; (2) outplanted into suspended cages for 1 week; (3) outplanted into grounded cages for 1 week. Recapture probabilities were estimated using Barker models. For treatments 2 and 3, recapture probabilities were calculated only for the period after day 7, when the abalone were released from the cages onto the substratum

	Time since outplanting (days)									
	1		3		7		10		14	
Treatment	p	SE	p	SE	p	SE	p	SE	p	SE
1	0.551	0.144	0.454	0.084	0.399	0.079	0.340	0.082	0.375	0.098
2							0.325	0.044	0.235	0.041
3							0.335	0.043	0.219	0.040

(Bower, 2000). However, the origin of this parasite is unknown and it has never been found in wild *H. kamtschatkana* populations nor at the hatchery from which the experimental abalone were procured (Bower, 2000). In the present study, survivorship of abalone in predator exclusion cages in the field was not significantly lower than for abalone held in hatchery tanks, and only a few individuals from these treatments died. The abalone that did die in the field cages showed no evidence of predator-induced shell or tissue damage. Thus non-predatory factors, possibly disease or parasitism, were responsible for some mortality, albeit this only accounted for a small proportion (1–2%) compared with that incurred among abalone outplanted directly to the substratum.

This study points to predators as the cause of mortality of newly outplanted *H. kamtschatkana*. During the first 7 days of the experiment almost all abalone outplanted into cages survived, whereas only 57.9% of abalone outplanted directly onto the open substratum survived. This finding is consistent with studies of other abalone species that suggested predators as important causes of post-outplanting mortality (Tegner and Butler, 1985; Schiel and Welden, 1987; McCormick *et al.*, 1994; Rogers-Bennett and Pearse, 1998; Dixon *et al.*, 2006). The most likely predators of outplanted large juvenile and adult *H. kamtschatkana* in British Columbia are the crabs *Cancer productus* and *C. magister*, the seastar *Pycnopodia helianthoides*, and the octopus *Octopus dofleini* (Sloan and Breen, 1988; Griffiths and Gosselin, 2008). In a separate experiment (Hansen, 2011), in which hatchery-reared *H. kamtschatkana* were outplanted to five field sites, followed by searches for dead individuals, 92 shells of dead abalone were recovered, most shells being found during the first 3 days after outplanting. Predators therefore do locate and kill abalone during the hours and days after outplanting. All shells collected were found free of flesh, with 34.7% being intact and the remainder having been broken. When considering only the Fleming Island site, 60.0% of recovered shells were unbroken and 40.0% were broken. Unbroken shells are indicative of seastar or octopus predation, whereas broken shells are indicative of crab predation (Tegner and Butler, 1985; Emmett and Jamieson, 1988; Griffiths, 2006). Although octopus are capable of drilling holes into shells, they generally leave abalone shells undamaged (Tegner and Butler, 1985; Emmett and Jamieson, 1988; Griffiths, 2006), and all abalone shells observed outside of octopus dens in this study were free of drill holes. Finally, fish predators such as cabezon and wolfeels tend to swallow small abalone whole and chip large abalone shells before swallowing, leaving behind both broken and unbroken shells with signs of acid etching (Tegner and Butler, 1985; Emmett and Jamieson, 1988; Griffiths, 2006). None of the shells collected during this study showed signs of acid etching. Of the predators capable of preying upon the size of abalone outplanted herein, the only predators that were observed over the course of this study, were *O. dofleini, P. helianthoides* and *C. productus*. Based on the condition of the recovered shells, it would appear that *C. productus* was responsible for approximately 40% of predator induced mortality, whereas *P. helianthoides* and *O. dofleini* together accounted for 60% of the predator-induced mortality of outplanted abalone. This is consistent with predator densities at the outplanting site, with *P. helianthoides* being more abundant (0.078 ± 0.029 individuals m^{-2}) than *C. productus* (0.009 ± 0.005 individuals m^{-2}).

The attempt to reduce outplanting mortality by providing a 1 week acclimation period was unsuccessful. The suspended and grounded cages did exclude predators, and survivorship within the cages was high. However, survivorship after the abalone were transferred to the substratum declined rapidly such that by day 14 there was no significant difference in survivorship among the three outplanting treatments. This finding suggests that methods other than predator exclusion devices are required to boost outplant survival.

The low survivorship reported here for outplanted juvenile *H. kamtschatkana* is problematic, as it substantially constrains the effectiveness of this approach for restoring wild populations of this endangered species. Predators were found to be the cause of virtually all post-outplanting mortality. The eventual use of juvenile or adult abalone outplanting to successfully restore wild populations is thus contingent on understanding why hatchery-raised abalone are considerably more vulnerable to predators than wild abalone and then developing means of reducing such vulnerability.

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