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Journal of Shellfish Research, Vol. 22, No. 3, 819–823, 2003.

ESTIMATING JUVENILE NORTHERN ABALONE (*HALIOTIS KAMTSCHATKANA*) ABUNDANCE USING ARTIFICIAL HABITATS

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ABSTRACT This study assesses the use of artificial concrete block habitats that provide standardized sample areas for measuring the abundance of northern abalone (*Haliotis kamtschatkana* Jonas) in comparison to 10 randomly selected 1-m^2 quadrant samples where all movable rocks were examined for cryptic abalone. A total of 278 abalone were measured within artificial structures and juvenile abalone (≤50 mm shell length, SL) were the most abundant size class. Juvenile abalone used artificial structures at greater mean densities (abalone/m^2) than nearby natural habitat (1.27 ± 0.25 SE versus 0.07 ± 0.09 SE) and emergent abalone (>50 mm SL) used artificial habitats at similar densities as they did in nearby natural habitats (0.38 ± 0.09 SE versus 0.44 ± 0.10 SE). Juvenile abalone abundance was significantly different between sites but not within sites, suggesting artificial structures showed promise in their ability to detect area specific differences in recruitment and to easily measure juvenile abalone abundance.

KEY WORDS: juvenile, abalone, cryptic, artificial habitat, recruitment, *Haliotis kamtschatkana*

INTRODUCTION

Northern abalone (*Haliotis kamtschatkana*) fisheries in British Columbia (BC) remain closed to commercial, recreational, and First Nations groups since 1990 due to conservation concerns (Campbell 2000). Dive surveys conducted by Fisheries & Oceans Canada (DFO) at index sites in BC estimated that northern abalone abundance had declined by more than 75% during 1978 to 1984 and continue to remain low (Breen & Adkins 1979 1981, Winther et al. 1995, Campbell et al. 2000). In April 1999, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed northern abalone as "threatened", meaning likely to become endangered if limiting factors are not reversed.

The most significant factors inhibiting northern abalone recovery are illegal harvests and poor recruitment (Campbell 2000). Recruitment, defined as the number of juvenile abalone growing and surviving to the adult population each year, may be insufficient as a result of critically low adult densities (Shepherd & Brown 1993, Shepherd & Partington 1995) that reduce reproductive success due to low fertilization of gametes (Allee et al. 1949). Other processes that may reduce abalone recruitment include variation in timing and intensity of gamete production, larval predation, and post-larval mortality (McShane 1992, 1995). Recruitment processes for northern abalone are not well understood (Breen 1986, Sloan & Breen 1988).

Increasing the abundance of existing wild northern abalone populations in BC is the long-term goal of the northern abalone national recovery strategy (Toole et al. 2002). One component of the strategy is to conduct abalone research and rebuilding experiments that may lead to increased breeding success, recruitment, and population densities. To evaluate the success of various rebuilding experiments, it will be necessary to measure changes in abalone recruitment by quantifying the abundance of juveniles.

Artificial collectors have been successful at measuring the intensity of abalone larval settlement (Keesing et al. 1995, Nash et al. 1995) but require high maintenance, a considerable time investment to sort samples and appropriate larval identification expertise. Other larval settlement survey techniques such as underwater magnification (Shepherd & Turner 1985), anesthesia (Prince & Ford 1985), and suction (McShane & Smith 1988) also require great diving and sample sorting efforts. In California, Davis (1995) used artificial concrete block habitats that provided standardized sample areas to monitor juvenile abalone recruitment. Comparing results from previous juvenile abalone surveys that required the destruction of natural habitat (Tegner et al. 1989), Davis (1995) was able to provide surrogate juvenile abalone habitat and produce an index of abalone recruitment.

This article describes the design and testing of artificial concrete block habitats over a 12-month period at 6 sites in Haida Gwaii (Queen Charlotte Islands), BC. The objectives were to determine if concrete block habitats provided surrogate habitat for juvenile northern abalone and if so, the ability of artificial habitats to quantify juvenile abalone abundance in different locations. To determine if juvenile abalone abundance within artificial habitats was representative of nearby natural habitats, invasive surveys of natural abalone habitats during the same time period were compared.

MATERIALS AND METHODS

Twenty-four artificial concrete block habitats were tested at 6 sites located at Lyell, Faraday and Murchison Islands (Fig. 1). These sites are within the Haida Gwaii Juan Perez Sound abalone stewardship area, where annual ecological assessments, abalone population surveys, and mark-recapture monitoring were conducted during 1998 to 2003 (Jones et al. 2003). The general area currently supports average densities of 0.35 emergent abalone/m^2 and 0.17 emergent youth (<70 mm shell length, SL) abalone/m^2 (Campbell et al. 2000).

The artificial habitat design used is a modification of that described by Davis (1995). Each habitat provides about 3.5 m^2 of surface area and consists of 24 concrete mini-blocks haphazardly oriented within a modified commercial crab trap (Fig. 2). Standard 20 cm × 20 cm × 40 cm concrete blocks were cut into quarters longitudinally to produce four individual mini-blocks. Discarded commercial crab traps measuring approximately 1 m in diameter and 0.3 m in height were altered by removing the central "fishing" component, leaving a structurally effective frame of corrosive resistant metal enclosed with stainless steel mesh. Diamond-shaped openings within the wire mesh frames were approximately 66 mm × 91 mm and tested with empty shells to confirm their permeability to abalone measuring less than 66 mm SL. Each structure also possessed a prefabricated entry or exit hole measuring 102 mm in diameter that was permeable to all abalone sizes and a hinged lid that allowed access to load, remove, and examine concrete mini-blocks during artificial habitat deployment and sampling.

In July 2001, 24 habitats were deployed by belaying each intact

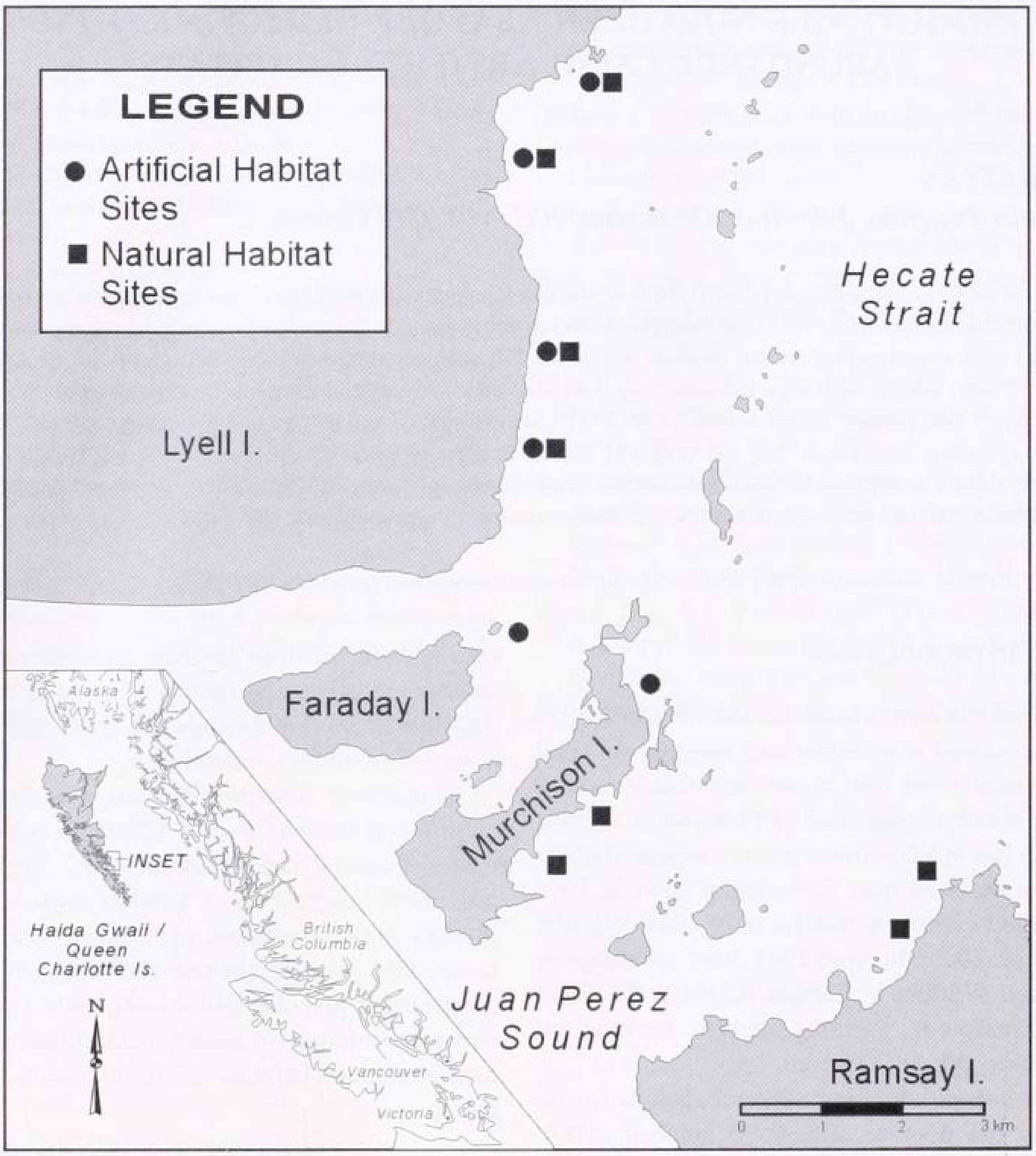

Figure 1. Artificial and natural abalone habitat study sites in northern Juan Perez Sound abalone stewardship area, Haida Gwaii, British Columbia.

unit from the dive support vessel to the ocean floor. Divers repositioned each structure with an industrial airlift bag. Within a site, 4 habitats were oriented parallel to shore in depths of 4 to 9 m and from 7 to 30 m apart. The habitats were randomly located within areas dominated by small boulders and cobble encrusted with red coralline algae. No anchoring mechanisms were used to secure the units in place, because each unit weighed approximately 120 kg and possessed a stable base.

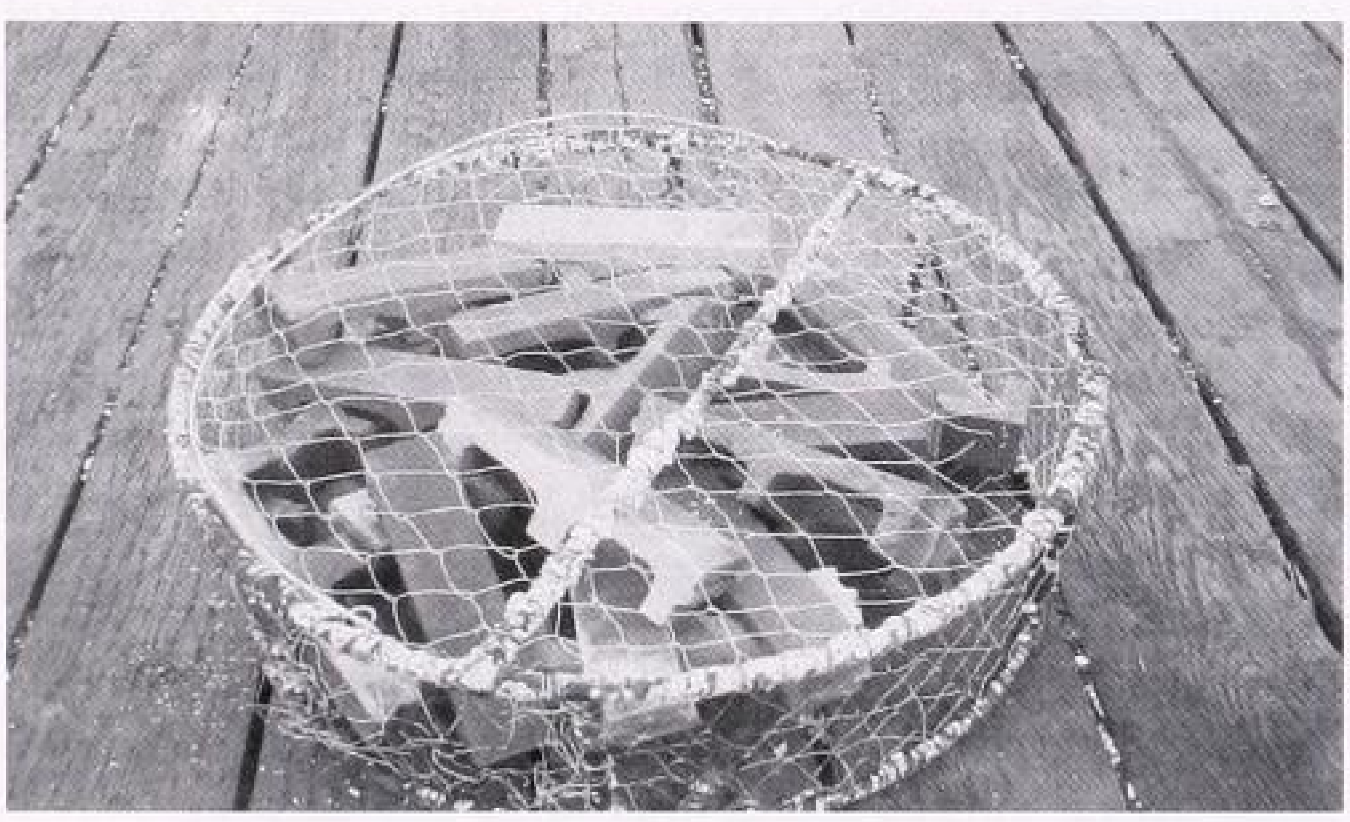

Figure 2. Artificial habitat design.

Divers visually inspected artificial concrete habitats for structural integrity in February 2002 and thoroughly surveyed each unit *in situ* during May and July 2002. A pair of divers sampled artificial habitats by removing and examining each concrete mini-brick for abalone. All abalone found were measured for maximum SL to the nearest millimeter and empty abalone shells were also measured and removed. After all bricks were examined, they were haphazardly repositioned within the metal frame. No special effort

TABLE 1.

Total number of abalone found in 4 artificial habitats at each of 6 sites during surveys in May and July 2002.

	May		July	
Site	Alive	Dead	Alive	Dead
1	17	1	24	1
2	44	1	38	4
3	5	2	3	2
4	12	0	10	1
5	37	3	31	0
6	37	3	20	1
Total	152	10	126	9

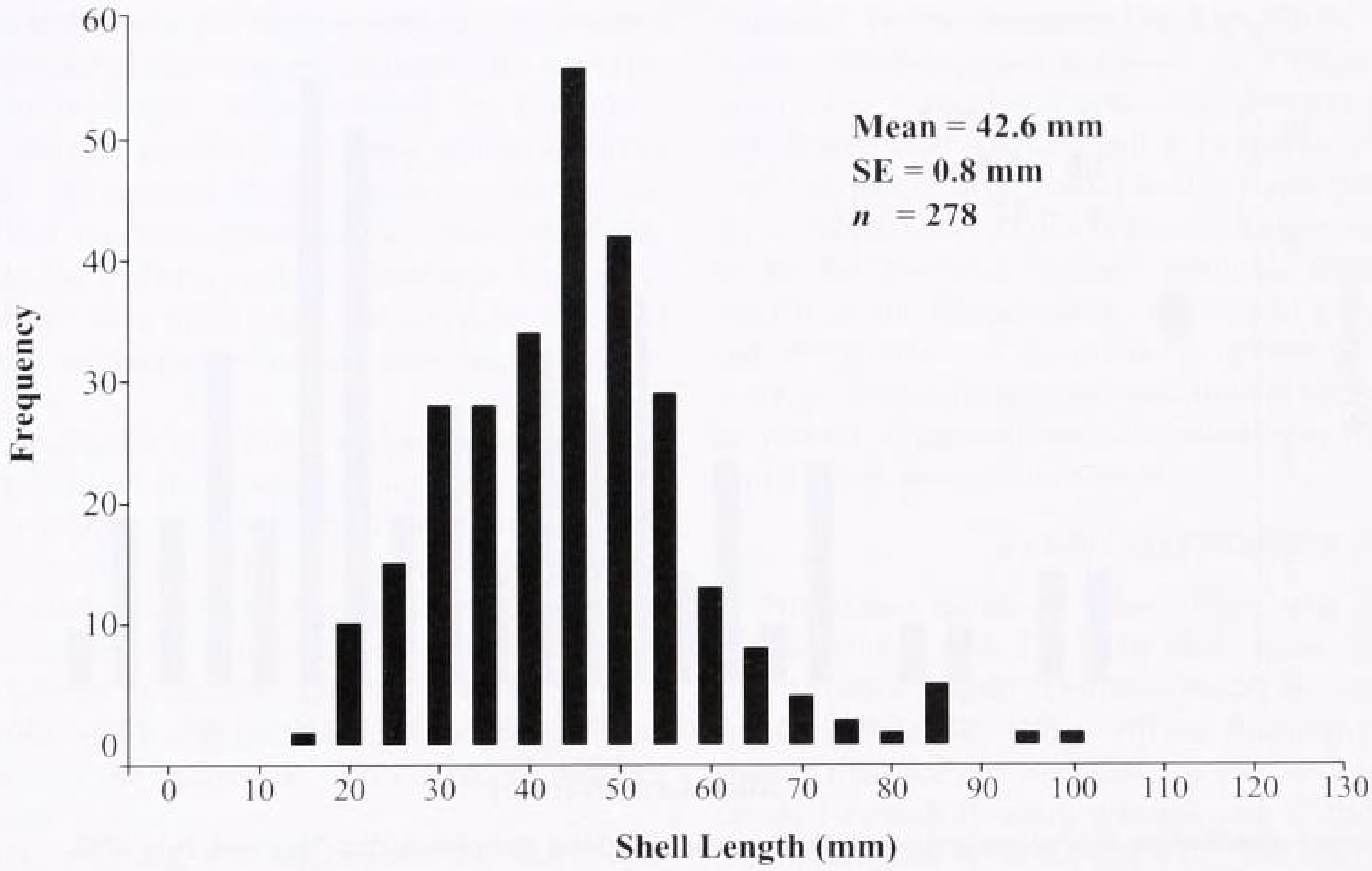

Figure 3. Size-frequency distribution of abalone measured within artificial habitats during May and July 2002.

was made to remove or monitor abalone adhering to bricks as the bricks were replaced back into the wire mesh containers.

To estimate the abundance of juvenile abalone occupying natural habitats, sampling was conducted within 10 m^2 of area at 4 artificial habitat sites and 4 additional random sites (see Fig. 1). At randomly selected locations throughout the available abalone habitat at each study site, divers invasively searched 10 1-m^2 quadrats for all hidden and exposed abalone. This method involved looking on the undersides of all movable rocks but did not include any destruction of natural habitat as care was taken to return any disturbed rocks to their original position. Diver efficiency in searching natural habitats was not measured.

RESULTS

All 24 artificial habitats contained abalone (n = 152, mean = 6.3 ± 0.95 SE abalone/container) during the first survey in May 2002, ten months after installation. During the second survey in July 2002, all but 2 artificial habitats contained abalone (n = 126, mean = 5.3 ± 0.87 SE abalone/container). There was no significant difference in mean abalone/container for either total abalone abundance (t-test, t = −0.84, d.f. = 46, $P > 0.406$) or total juvenile abalone (≤50 mm SL) abundance (t-test, t = −0.47, d.f. = 34, $P > 0.643$) between the two sample periods.

A total of 278 abalone and 19 empty shells were counted and measured within artificial habitats during the study (Table 1). Juvenile abalone (≤50 mm SL) accounted for 75.4% (n = 224) of all those measured, while only 3.6% (n = 15) were more than 70 mm SL and considered to be mature. The smallest and largest abalone found in artificial structures were 15 mm and 100 mm SL. The average abalone size was 42.6 mm SL (Fig. 3) and 56.4 mm SL for all empty shells. On average, each artificial habitat required 12.5 min for a pair of divers to completely survey.

The mean density of juvenile, mature, and all-sized abalone within artificial habitats was 1.27, 0.06, and 1.65 abalone/m^2, respectively (Table 2). Juvenile abalone densities in artificial habitats were significantly different between sites (one-way ANOVA, F = 8.409, d.f. = 5,35, $P < 0.001$), but not within sites, suggesting differential recruitment to these locations.

A total of 82 abalone were counted and measured within natural habitat samples. Juvenile abalone accounted for 13.4% (n = 11) of all those measured, while 64.6% (n = 53) were mature. The smallest and largest abalone found in natural habitats were 14 mm and 124 mm SL. The average abalone was 79.3 mm SL (Fig. 4) and 75.2 mm SL for empty shells. Mean abalone densities during the May and July surveys were similar (ANOVA, F = 0.819, d.f. = 1,15, P = 0.38) and there was no difference in total abalone densities between artificial habitat sites (sites 1–6) and additional random sites (sites 7–10). The mean density of juvenile, mature and all-sized abalone measured with natural habitats were 0.07, 0.33, and 0.51 abalone/m^2, respectively, (Table 3). Natural habitat samples were located at a mean depth of 3.08 ± 0.08 m datum (min = −0.4 m, max = 4.8 m).

Juvenile abalone densities measured within artificial habitats were compared with natural habitat samples. At sites 1 to 4, where

TABLE 2.

Mean number and densities (#/m^2) of abalone in 4 artificial habitats at each of 6 sites surveyed in May and July 2002.

Site	No. of Abalone	Abalone Density (#/m^2) ≤50 mm SL	>70 mm SL	All Sizes
1	20.5	1.00	0.00	1.46
2	41.0	2.14	0.14	2.93
3	4.0	0.29	0.00	0.29
4	11.0	0.39	0.18	0.79
5	34.0	2.25	0.00	2.43
6	28.5	1.64	0.04	2.04
Mean	23.2	1.27	0.06	1.65
SE	4.1	0.25	0.03	0.29

Standard errors shown are for site groups (n = 12).

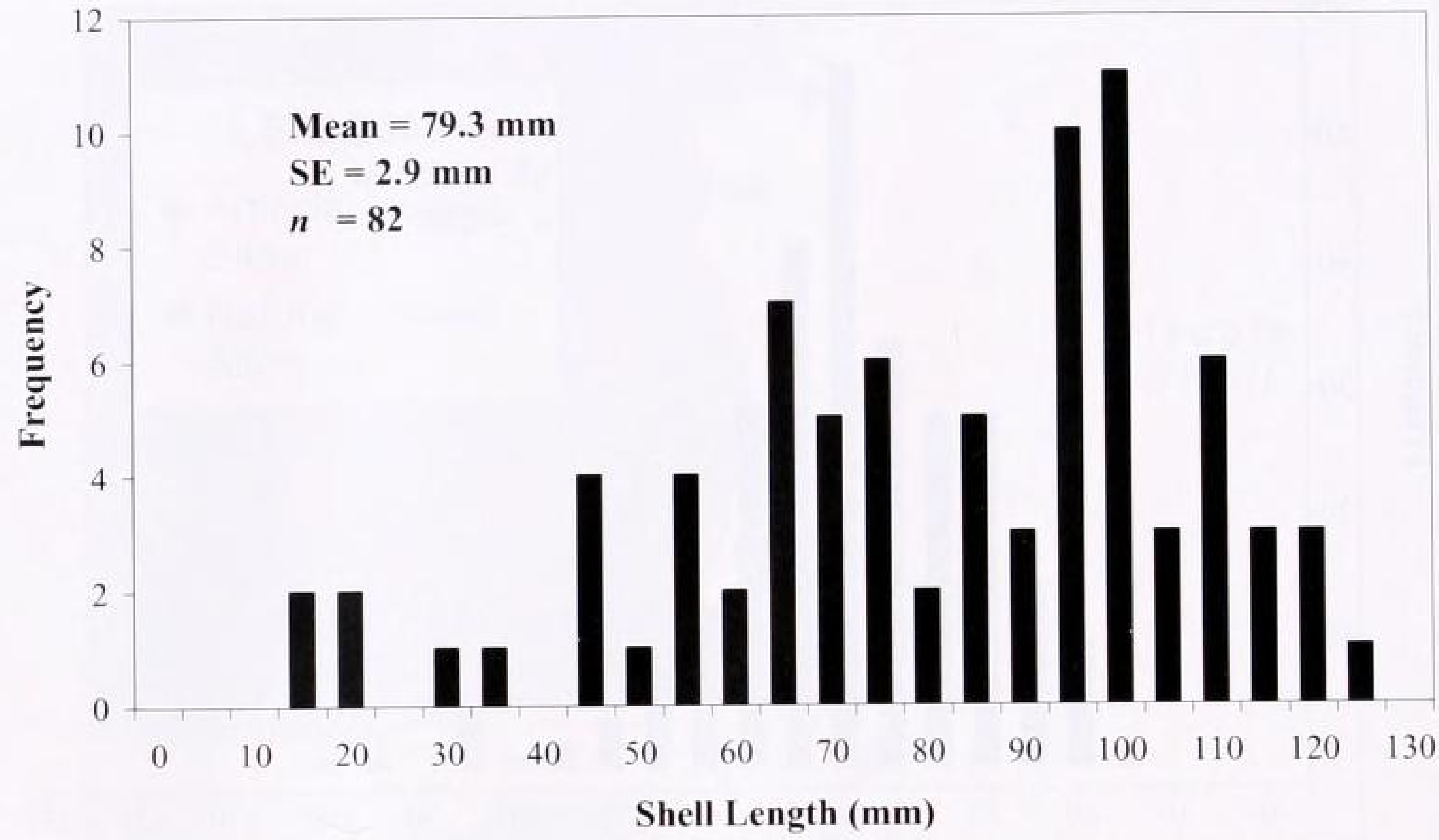

Figure 4. Size-frequency distribution of abalone measured within natural habitat samples during May and July 2002.

both artificial and natural habitat samples were conducted within an area greater than 10,000 m^2, juvenile abalone densities measured within artificial habitats were significantly greater than those within natural habitat samples (*t*-test, $t = 3.049$, d.f. $= 14$, $P = 0.009$). When all locations were included in the comparison, juvenile abalone densities measured within artificial habitats remained significantly greater than those within natural habitat samples (*t*-test, $t = 5.597$, d.f. $= 26$, $P < 0.001$). There was no significant difference in juvenile abalone densities measured in natural habitats at sites 1 to 4 when compared with sites 7 to 10, indicating that the presence of artificial structures at sites 1 to 4 did not influence juvenile abalone abundance in surrounding natural habitats.

DISCUSSION

The artificial habitat design tested in this study provided surrogate habitat for both juvenile and mature northern abalone. Within 10 months of installation, native abalone had discovered and occupied each of the 24 artificial habitats. The similar number of abalone occupying artificial habitats in July suggested the concrete blocks continued to provide preferred shelter throughout the summer months when surrounding food abundance is high and good quality alternative natural habitats were available. The specific length of time required for artificial materials to condition and attract abalone was difficult to determine due to the limited number of sample periods. The concrete materials appeared to be suitable for northern abalone within 7 months based on observations of abalone occupying most artificial habitats during structural inspections in February 2002. The conditioning time of this material was consistent with Davis (1995) who found "juvenile native *H. rufescens* and *H. corrugata* inhabited artificial habitats within 4 months of deployment" in California.

TABLE 3.

Mean number and density (#/m^2) of abalone in 10 natural habitat samples at each of 8 sites surveyed in May and July 2002.

Site	No. of Abalone	Abalone Density (#/m^2) ≤50 mm SL	>70 mm SL	All Sizes
1	8.0	0.15	0.45	0.80
2	1.0	0.05	0.45	0.65
3	6.5	0.05	0.10	0.30
4	3.0	0.00	0.25	0.35
7	3.5	0.05	0.55	0.60
8	6.0	0.05	0.40	0.60
9	6.0	0.20	0.35	0.70
10	7.0	0.00	0.10	0.10
Mean	5.1	0.07	0.33	0.51
SE	2.99	0.09	0.07	0.10

Standard errors shown are for site groups ($n = 16$).

As indicated in Figure 3, juvenile abalone were the most abundant size class occupying artificial habitats. Both the small mesh size and high substrate complexity may have contributed to the size selectivity by limiting access and suitable shelter for abalone greater than 70 mm SL. Juvenile abalone densities measured within artificial habitats were significantly different between sites but similar within sites. This apparent ability of artificial structures to quantify juvenile abalone abundance within standardized sample areas at different locations may provide the feedback required to gauge the success of future stock restoration experiments. Benefits of the modular artificial habitat design tested here included the low cost of construction, ease of deployment, durability within high energy subtidal environments, and most importantly, their ease of being dismantled and reconstructed by divers *in situ*, without the destruction of natural habitat.

In this study, juvenile abalone recruitment measured within artificial habitats was not representative of recruitment measured within nearby natural habitat samples. At sites 1 to 4, juvenile abalone abundance measured within artificial habitats was significantly greater than natural habitat samples, ranging in magnitude from 4.3 times greater at site 3 to 42.9 times greater at site 2. Although each natural habitat sample was randomly located within good quality juvenile abalone habitat and the mean juvenile abalone density found within natural habitats was similar to Campbell et al. (2000), natural habitats provided little consistency with substrate composition and hence, the lower abundance of sheltered habitat. Specific factors that made the artificial structures attractive to abalone were not investigated experimentally but were likely due to the consistent and availability of good quality sheltered habitat provided by the concrete blocks. Based on observations, additional factors that may have influenced the abundance of abalone in artificial habitats included easily accessed algal food growing on concrete bricks and a mesh frame that may have excluded large predators such as Sunflower seastars (*Pycnopodia helianthoides*).

The measured abundance of juvenile abalone within artificial habitats may have been at their annual spring peak, as surveys were only conducted during May and July, a similar time of year that Davis (1995) measured a peak in abalone recruitment. To calibrate artificial habitats into better juvenile abalone abundance instruments, it will be necessary increase the number of surveys and monitor fluctuations in abalone abundance throughout the year. Only by comparing the changes in abalone abundance from winter to summer can the magnitude of localized recruitment events be determined.

The use of artificial habitats as a standardized sampling instrument to estimate the abundance of cryptic juvenile abalone was supported by this research. The haphazardly oriented concrete blocks provided preferred habitat for juvenile abalone and the metal frame covered with wire mesh provides structural integrity and allowed each sampling unit to be quickly deployed or repositioned. A pair of divers could easily sample units *in situ*, with no destruction to either natural habitat or abalone adhering to concrete bricks. For proposed abalone rebuilding experiments, artificial habitats of this design can be used as an initial release site for cultured juveniles, as an affordable method of determining baseline juvenile abundance along coastlines of interest, and as a means to quantify changes in juvenile recruitment that may be due to experimental stock enhancement.

ACKNOWLEDGMENTS

The author thanks the many divers who participated during field activities. Alan Campbell, Russ Jones, and Ron Ydenberg who provided helpful comments during the experimental design and analysis stages. This work was financially supported by the Haida Tribal Society, Fisheries and Oceans Canada's Subvention Grants Research Program, Environment Canada's Habitat Stewardship Program for Species at Risk, and the Centre for Wildlife Ecology at Simon Fraser University.

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