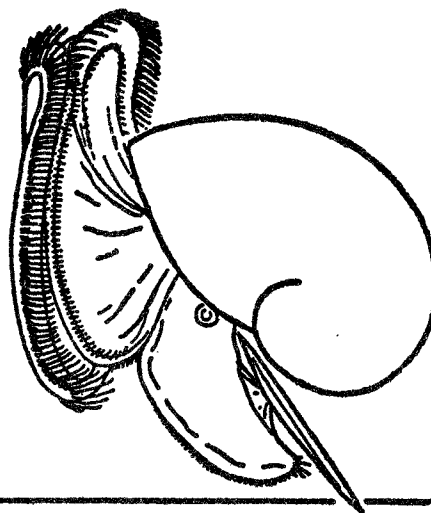


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ORDER, Suborder, DIVISION, Subdivision, SECTION,
SUPERFAMILY, FAMILY, Subfamily, Genus, (Subgenus)
New Taxa

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Subtidal Abalone Populations in an Area Inhabited by Sea Otters

BY

JOHN COOPER¹, MARK WIELAND¹ AND ANSON HINES²

(2 Text figures)

INTRODUCTION

LOWRY & PEARSE (1973) determined the population structures and densities in 1972 of 2 species of abalones, *Haliotis rufescens* Swainson, 1822 and *H. walallensis* Stearns, 1899, in the sea otter-inhabited kelp forest at Hopkins Marine Station, Pacific Grove, California. In their study, abalones, as well as sea urchins, were almost always found living in crevices more or less inaccessible to sea otters (*Enhydra lutris* Linnaeus, 1758), and the densities were low in contrast to conditions before sea otters became re-established, when the bottom "... was covered with urchins and abalones spaced only a few feet apart ..." (MCLEAN, 1962). The size-frequency distribution of *H. rufescens* found by LOWRY & PEARSE (*op. cit.*) is one of a broad spectrum lacking any distinct modes and reflecting the year-round spawning of this species (BOOLOOTIAN *et al.*, 1962; YOUNG & DEMARTINI, 1970). Although we are aware of nothing published on the reproductive cycle and settlement of *H. walallensis*, LOWRY & PEARSE (*op. cit.*) found this species had a size-frequency distribution with a single, sharp mode at 7.4 cm. They suggested that this peak represented a single age-class and hypothesized that *H. walallensis* achieves successful settlement irregularly.

This paper re-examines the densities, population structures and distributions of abalones in the kelp forest at Hopkins Marine Station to see if any changes have occurred since the Lowry & Pearse study. In addition, we test the hypothesis that the single size-frequency mode found by LOWRY & PEARSE (1973) for *Haliotis walallensis* represents a single age-class by looking for a shift in

the mode to a larger size. If the hypothesis were correct, such a shift would reflect continued growth of the abalones in this year-class over the last 4 years, and the appearance of any additional mode in the size-frequency distribution would reflect new successful settlement.

MATERIALS AND METHODS

This study was conducted at the Hopkins Marine Life Refuge, Pacific Grove, California. The study area encompassed 1600 m² and was centered at the "100 meter mark" on the black electric cable which runs through the kelp forest adjacent to Hopkins Marine Station (see Figure 1). This area is between and overlaps the 2 transect lines used by LOWRY & PEARSE (1973). *Haliotis rufescens* and *H. walallensis* were counted and measured *in situ* on scuba dives during July and August, 1976. The 2 species were identified according to Cox (1962) and were distinguished under water by the differences in mantle edge coloration. Densities of the abalones were estimated by counting individuals within 10 m² circular plots located by coordinates from a random number table. Notes were taken on the occurrence of abalones within and out of crevices. Abalone sizes were obtained by swimming over the study area and systematically recording maximum shell lengths to the nearest 1 centimeter using calipers. Densities and size-frequency distributions thus obtained were compared with those obtained by LOWRY & PEARSE (1973).

RESULTS

The mean combined density of both species of abalones was 0.16 per m² (s. d. = ± 0.24; n = 25 plots). The

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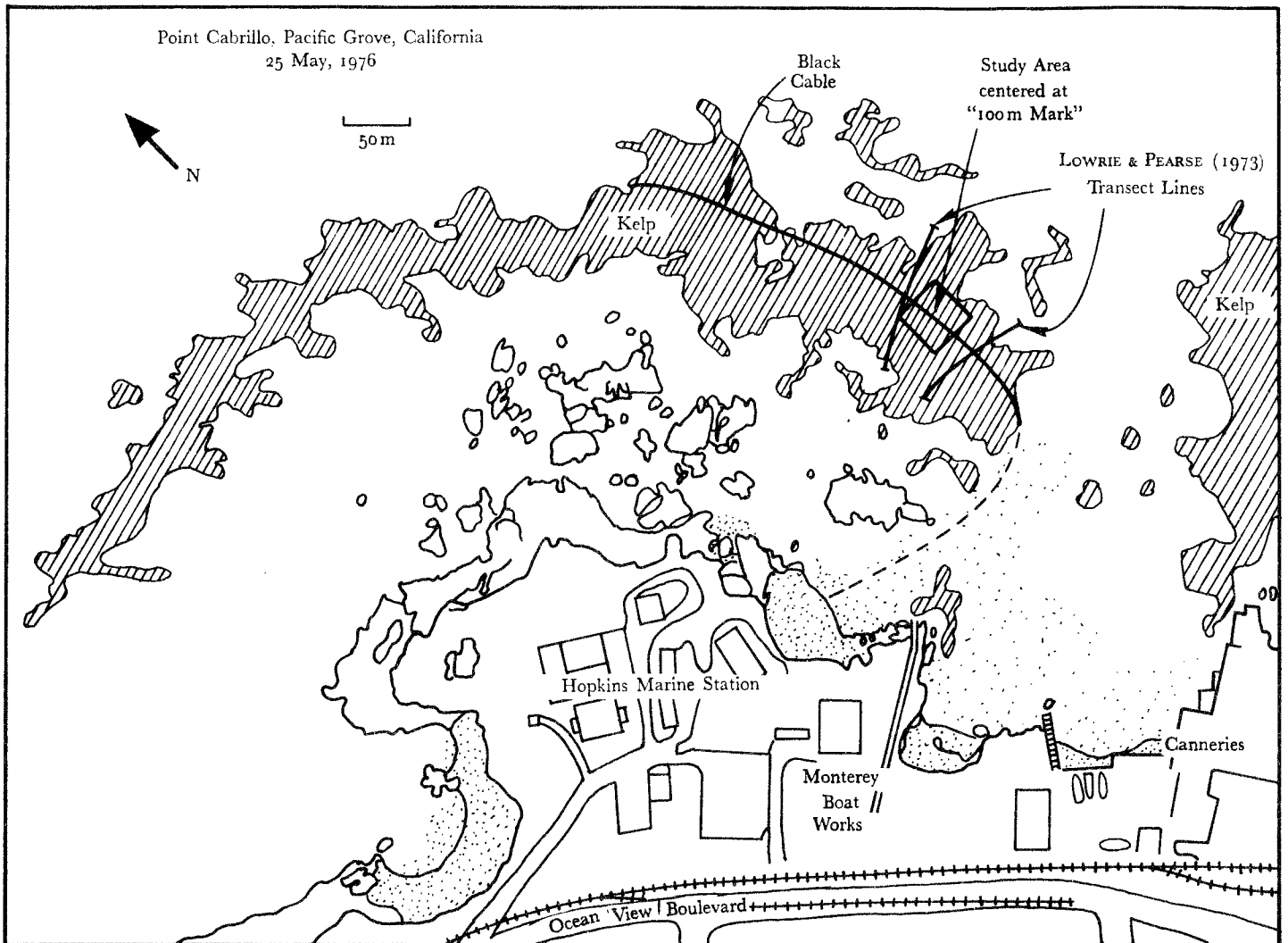


Figure 1

Map of Point Cabrillo, Pacific Grove, California, USA, showing the study area adjacent to Hopkins Marine Station and the location of transect lines used by LOWRY & PEARSE (1973). The "black cable" is an abandoned heavy electric cable, useful as a reference when diving.

density of *Haliotis rufescens* was 0.08 ± 0.14 per m^2 and of *H. walallensis* was 0.08 ± 0.12 per m^2 . These data are not significantly different from those of LOWRY & PEARSE (1973) (Student t-test, $p > 0.10$) (Table 1).

All individuals observed during this study were crevice-inhabiting, and *Haliotis walallensis* were subjectively judged to be found in shallower cracks than *H. rufescens*.

The size-frequency distribution of *Haliotis rufescens* showed no distinguishable modes over a broad range of sizes, while *H. walallensis* showed a single, distinct mode at 7.5 cm (Figure 2). These frequency distributions are not significantly different from those found by LOWRY & PEARSE (1973) (Kolmogorov-Smirnov test, $p > 0.20$) (see Figure 2).

Table 1
Densities of Abalones ($\bar{X} \pm 1$ s.d. per m²)

	<i>Haliotis</i> spp.	<i>Haliotis rufescens</i>	<i>Haliotis walallensis</i>
Lowry and Pearse (1973) (N = 45 1×10m swath counts)	0.21 ± 0.34	0.15	0.07
This paper (1976) (N = 25 10m ² circular quadrats)	0.16 ± 0.20	0.08 ± 0.14	0.08 ± 0.12

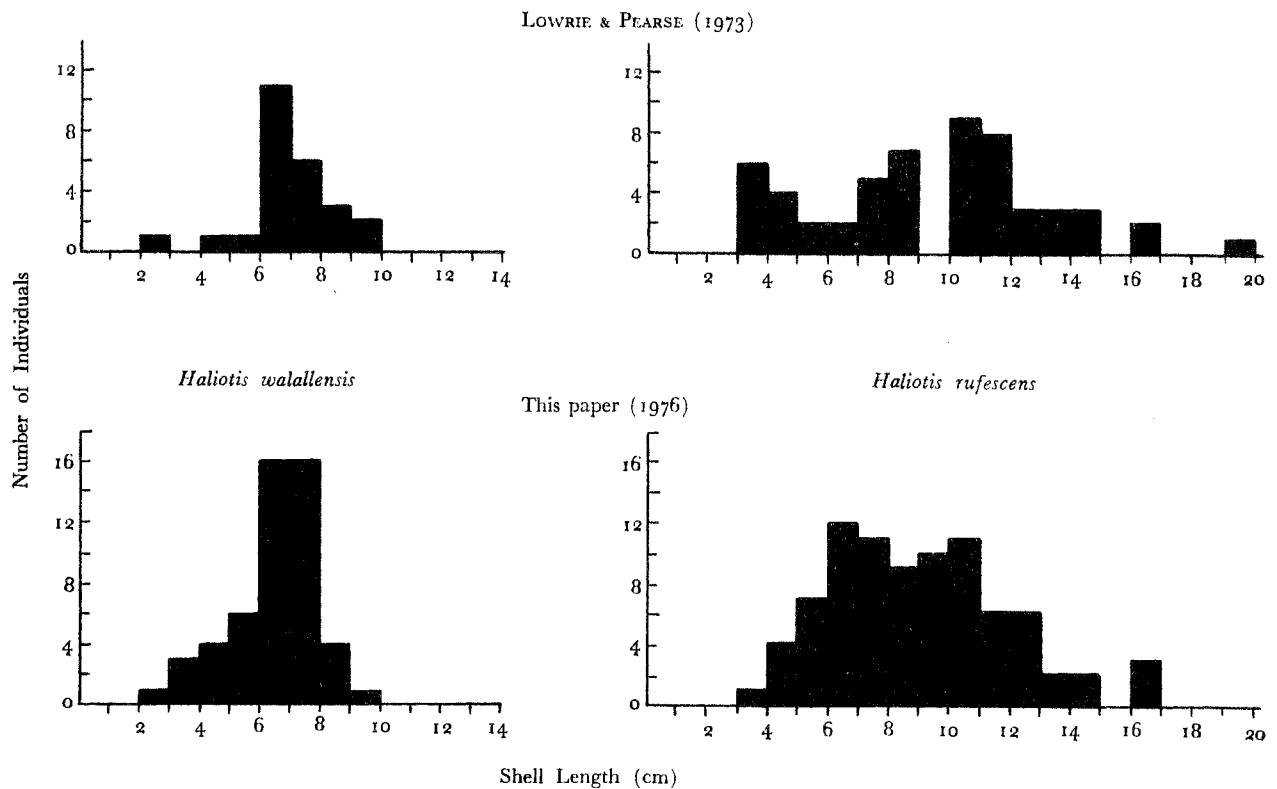


Figure 2

Size-frequency distributions of *Haliotis walallensis* and *Haliotis rufescens* off Hopkins Marine Station in the present study (summer, 1976) and in LOWRY & PEARSE (1973; data collected in November, 1972). The distributions from the two dates are not significantly different (Kolmogorov-Smirnov test, $p > 0.20$).

DISCUSSION

The densities of *Haliotis rufescens* and *H. walallensis* have remained quite constant over the last 4 years since they were measured by LOWRY & PEARSE (1973). The slight differences in densities between LOWRY & PEARSE (*op. cit.*) and the present paper may be a result of the differences in sampling methods. Lowry & Pearse used belt transects (total sampling area = 3 560 m²), while we used random quadrats in a smaller study area. One of their transects had densities (westline = 0.17 per m²) virtually identical to those in the present study, while the other transect densities were somewhat higher (eastline = 0.35 per m²), resulting in a slightly higher overall mean density (0.21 per m²). This stability, coupled with the observation that abalones in the study area continue to be found only in crevices, supports the contention that the crevice-dwelling populations have established a refuge from sea otter predation. Sea otters are, however, continuing to feed on abalones, as well as a wide variety of other invertebrates in Hopkins Marine Life Refuge (Dan Costa, personal communication). Other predators in the area, including sea stars (*Pycnopodia helianthoides* (Brandt, 1835); *Pisaster giganteus* (Stimpson, 1857); and *Orthasterias koehleri* (de Loriol, 1897)), octopuses (*Octopus* spp.), rock crabs (*Cancer antennarius* Stimpson, 1856), and cabezone (*Scorpaenichthys marmoratus* Ayres, 1854), are known to feed on abalone, and all of these predators have ready access to the crevices inhabited by abalone (COX, 1962; FEDER, 1963; O'CONNELL, 1953; personal observations). However, abalones have evolved behavioral responses (clamping down, "running," shell twisting, secretion of mucus, etc.) which minimize their capture (FEDER, *op. cit.*; MONTGOMERY, 1967; personal observations). During other studies in the area, abalones smaller (< 3 cm) than most of those observed in this study have been found on open, exposed surfaces (LOWRY & PEARSE, 1973; Hines & Pearse, unpublished observations). It would be interesting to know if only those recruits which settle in crevices survive, or if abalones settle everywhere and later move into crevices. Our observations agree with LOWRY & PEARSE (*op. cit.*) that *H. walallensis* is found in smaller, that is shallower, cracks than *H. rufescens*. It would also be interesting to know if this difference in crack distribution is the result of competition between the 2 species, differences in crack preference, or perhaps simply a reflection of small abalones (both *H. walallensis* and smaller *H. rufescens*) tending to occur in smaller cracks.

The size-frequency distribution of *Haliotis rufescens* found in this study and that of LOWRY & PEARSE (1973) lack any distinct modes over a wide size range. This is expected from the year-round spawning of this species (BOOLOOTIAN *et al.*, 1962; YOUNG & DEMARTINI, 1970). However, the size-frequency distribution of *H. walallensis* in the present study is also identical to that found 4 years ago by LOWRY & PEARSE (*op. cit.*) with a single, distinct mode at 7.5 cm. This unchanged size-frequency distribution does not support the hypothesis that the *H. walallensis* observed by Lowry & Pearse represented a single age-class resulting from a single earlier successful settlement. Rather, as with *H. rufescens*, *H. walallensis* at Hopkins Marine Life Refuge appears to be in a stable size (age) distribution. LOTKA (1922) showed that a population with constant survivorship and birth rates will reach and maintain a stable age distribution. The stable size (age) distribution of *H. walallensis* and *H. rufescens* thus suggests constant survivorship and recruitment rates for these populations, with recruitment into each size (age) class balanced by losses due to mortality and growth (aging). Finally, it is interesting to note that only one abalone measured in the LOWRY & PEARSE (*op. cit.*) study and none in the present study was larger than legal size (7 inches or 170 mm).

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We gratefully acknowledge John S. Pearse for his support and constructive reading of the manuscript. Donald P. Abbott gave generously of the facilities of Hopkins Marine Station, Stanford University. Dan Miller of California Department of Fish and Game provided the aerial photograph used for Figure 1. This work was supported by Sea Grant NOAA 04-6-1584402 to John S. Pearse.

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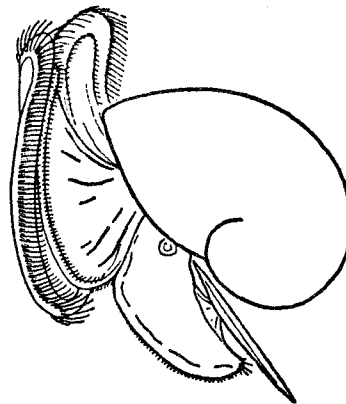
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