

1 **OYSTER GROW-OUT CAGES FUNCTION AS ARTIFICIAL REEFS FOR**
2 **TEMPERATE FISHES**

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4 Jessica C. Tallman and Graham E. Forrester*

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6 Department of Natural Resources Science, University of Rhode Island, Kingston, RI

7 02881, USA

8

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10 *Corresponding author: gforrester@uri.edu

11 **Abstract**

12 We compared relative fish density, growth and disappearance rates (mortality
13 plus emigration) on 3 oyster grow-out sites, 6 natural rocky reefs, and 1 artificial reef
14 purposely built for fish habitat. All sites were located within Narragansett Bay, Rhode
15 Island. Trap surveys were conducted in the summer and autumn of 2004 and 2005
16 using a range of trap types designed to sample juvenile and adult fishes. Cunner,
17 *Tautogalabrus adsperus*, were more abundant on natural rocky reefs and the artificial
18 reef than on oyster grow-out sites, whereas scup, *Stenotomus chrysops*, and tautog,
19 *Tautoga onitis*, displayed the opposite pattern and were most abundant on aquaculture
20 sites. The relative density of black sea bass, *Centropristis striata*, was similar in all
21 habitats. A mark-recapture study on scup indicated that this species grew at higher
22 rates on natural rocky reefs, but had a lower disappearance rate from aquaculture sites.
23 Based on these criteria, the oyster grow-out cages provide good quality habitat for
24 fishes typically associated with hard-bottom habitats. Habitat restoration programs for
25 these fishes should thus consider grow-out cages alongside other types of artificial reef.

26 **Introduction**

27 Sea grass and macroalgae beds, marsh creeks, cobble and rocky reefs, and
28 shellfish beds are often described as key inshore fish habitats, and the loss or
29 degradation of these habitats is implicated in the decline of many coastal fisheries (Beck
30 et al. 2001). Shellfish beds provide a good example of an inshore habitat much
31 diminished in extent. Shellfish beds were once widespread in inshore habitats along the
32 US east coast (MacKenzie 1997), including Narragansett Bay and several south shore
33 salt ponds of Rhode Island (Oviatt et al. 2003). Like in most coastal Atlantic states
34 (Ford 1997), oyster harvests in Rhode Island have declined by 90% over the past
35 century (Rhode Island Aquaculture Initiative 2004), with a concomitant decline in the
36 area of oyster bed habitat (MacKenzie 1997; Oviatt et al. 2003). Decline of oysters has
37 been attributed to several factors including pollution, harvest pressure, disease, and
38 severe storms (Seliger et al. 1985; Rothschild et al. 1994; Ford and Tripp 1996).

39 The complex three-dimensional structure of oyster beds provides habitat for a
40 diversity of benthic organisms (Lenihan & Peterson 1998; Rodney and Paynter 2006).
41 These benthic species, in turn, provide prey resources for fin fishes and other mobile
42 consumers (Kaiser et al. 1998; Peterson et al. 2003). The restoration of oyster beds
43 may thus have both fishery-related and ecological benefits (Mann and Harding 1997;
44 Breitburg et al. 2000). Oyster aquaculture is a promising way to restore the economic
45 benefits of oyster harvesting. Typically, part of the aquaculture process involves
46 suspending juvenile oysters above the bottom in shallow water where they grow to
47 market size (Rheault and Rice 1995; Powell 1996). In Rhode Island, oysters are often
48 held in tiered racks that are placed on unvegetated soft sediment (Rheault and Rice

49 1995). The racks thus provide a complex three-dimensional structure that remains on
50 the bottom continually, except when racks are briefly removed from the water every 3-6
51 months to harvest legal-sized oysters. In 2005, grow-out cages at 25 sites covered 35
52 hectares of subtidal habitat in Rhode Island.

53 The few surveys of macrofaunal communities on oyster grow-out cages
54 (Luckenbach et al. 2000; Dealteris et al. 2004; O'Beirn et al. 2004), and anecdotal
55 reports by SCUBA divers (D. Hudson, University of Rhode Island, and R. Rheault,
56 Moonstone Oysters, personal communication), revealed that grow-out cages are
57 colonized by some finfish. These finfish typically occupy natural rocky-reef habitats,
58 raising the possibility that oyster grow-out cages provide habitat for these species and
59 effectively act as artificial reefs. Artificial reefs deliberately designed to mimic natural
60 rocky reefs are widely used. A common motivation for their deployment is to enhance
61 the production of reef-associated species (Seaman and Sprague 1991; Pratt 1994).
62 Enhanced production will occur if the availability of natural rocky reefs is limited, so that
63 adding artificial habitat increases overall fish abundance (Bohnsack 1989). The extent
64 of natural rocky reef habitat in Narragansett Bay is little known, but existing data
65 suggest that virtually all of the 380 km² of subtidal habitat in the bay is soft sediment
66 (McMaster 1960; Poppe 2003; Tiner et al. 2004).

67 Evaluating the performance of artificial reefs must include contemporaneous
68 comparisons with the natural reefs they are designed to mimic (Carr and Hixon 1997).
69 Although oyster grow-out cages are not designed to mimic natural rocky reefs, providing
70 habitat for finfish would constitute an important, albeit unintentional, side-effect of their
71 deployment. Consequently, we tested the hypothesis that oyster cages provide fish

72 habitat that is functionally equivalent to natural rocky reef habitats and artificial reefs
73 specifically designed to mimic natural rocky reef. To assess functional equivalence, we
74 compared the relative density, growth, and disappearance rates (mortality plus
75 emigration) of finfish captured on oyster grow-out cages to equivalent measures of fish
76 occupying nearby natural rocky reefs and one artificial reef. The study focused on four
77 economically valuable or ecologically significant finfish species known to inhabit both
78 natural rocky reefs and oyster grow-out cages: (1) black sea bass, *Centropristis striata*;
79 (2) cunner, *Tautogalabrus adspersus*; (3) scup, *Stenotomus chrysops*; and (4) tautog,
80 *Tautoga onitis*.

81 **Methods**

82 *Study sites*

83 The study was conducted in Narragansett Bay, Rhode Island, in 2004 and 2005
84 (Figure 1). We studied three habitats: oyster aquaculture sites, natural rocky reefs, and
85 an artificial reef. The three aquaculture lease sites were located in areas where the
86 seabed was soft-sand or silt-clay. Leases had been active for several years prior to this
87 study. Juvenile cultured eastern oysters (*Crassostrea virginica*) were held in mesh bags
88 on tiered racks inside a mesh cage (1.8 m x 0.6 m x 0.6 m). Each cage was attached to
89 one of several trawl lines that ran the length of the lease. Each aquaculture site was in
90 water 4-8 m deep and contained approximately 100 cages spread over 0.8 to 1.6 ha.
91 The six natural rocky reef sites were outcroppings of natural rock (mostly granite)
92 covered with algae and located between 4 and 9 m deep. Some reefs were offshore
93 and ranged in area between 0.4 and 0.8 ha, whereas other reefs, similar in size,
94 adjoined land. The single artificial reef was built in 1997 and designed to mimic local

95 natural rocky reefs and provide lobster habitat (Castro et al. 2000). Six modules (each
96 10 m x 20 m) of granite cobbles were positioned approximately 33 m apart in water 5 m
97 deep. Each module was divided into two 10-m x 10-m halves; one of which was
98 constructed from cobbles (10 to 20-cm in diameter) and the other was constructed of
99 larger rocks (21 to 40 cm in diameter). Overall, the six modules provided 0.16 ha of
100 habitat (Castro et al. 2000, Robbins 2004).

101 We sampled the same three aquaculture sites and artificial reef in both 2004 and
102 2005, whereas the number of natural rocky reefs increased in the second year (Fig. 1).
103 The 3 aquaculture and 5 natural rocky reef sites were interspersed spatially, and were
104 all within 5 km of each other (Fig. 1), so we considered them comparable as statistical
105 replicates. Trap sampling was conducted from mid-July through early-October in both
106 years. In 2004, there were two sampling sessions, separated by three weeks. In 2005,
107 there were three sampling sessions, with just over two weeks separating them. The
108 sampling dates were as follows: Session 1, 2004: 26 June – 20 August; Session 2,
109 2004: 15 September – 10 October; Session 1, 2005: 11 July – 29 July; Session 2, 2005:
110 15 August – 29 August; Session 3, 2005: 19 September – 6 October.

111 *Trapping methods*

112 We used several types of traps to ensure that we captured fish of a range of
113 sizes. Trapping in 2004 utilized six commercial black sea bass pots (International
114 Marine Marketing, Wakefield, Rhode Island) and three O-pots built to Robbins (2004)
115 specifications. The O-pots were cylindrical, with a diameter of 91 cm and a height of 61
116 cm. They had two opposing “wrap-in” V entrances, 61 cm high and 3.8 cm wide. For
117 the 2005 field season, we used 30 O-pots similar in shape to the 2004 O-pots except

118 that each exterior dimension was reduced by 25%. O-pots and black sea bass pots
119 were covered with 1.3 cm plastic mesh. In 2005, we also used 18 Gee minnow traps
120 (Memphis Net and Twine, Memphis, Tennessee) to more effectively sample age-0 fish.
121 Minnow traps (23 cm x 44 cm) were made of 0.64 cm galvanized steel wire with two
122 entrances (each 2.5 cm in diameter).

123 All traps were baited with frozen whole clam bellies and were placed to sit
124 undisturbed on the seafloor (soak) for 2 d, though some soaked for up to 5 d when
125 inclement weather delayed retrieval. In 2004, because we had only 9 traps, we divided
126 the six sites into two groups of three and sampled each group on alternate dates
127 (allocating 3 traps per site per date). In 2005, we simply divided the traps among the
128 nine sites and sampled continually at all sites (5 traps per site per date). Traps were
129 deployed and retrieved between 0800 and 1600 hours.

130 *Mark-recapture methods*

131 Once traps were retrieved, individuals of the four study species were placed in
132 water-filled bins on the boat and anesthetized in dilute ethyl 3-aminobenzoate. All fish
133 were measured to the nearest millimeter. For comparability with previous work on these
134 species, we measured standard lengths (SL) of black sea bass, tautog, and cunner, and
135 fork lengths (FL) of scup. After measuring, we tagged all fish greater than 71 mm SL
136 (or, if scup, FL) in 2004 and all fish greater than 109 mm FL in 2005. Fish were tagged
137 with numbered anchor tags (Floy Tag[®] types FF-94 and FD-68B FF; Floy Tag[®], Seattle,
138 Washington). All fish were allowed to recover from the anesthetic before being released
139 at their point of capture.

140 *Relative fish density*

141 We used the number of fish caught per trap as an index of relative density, which
142 assumes that traps sample an equal volume of water with equal efficiency in all three
143 habitats. We tested for effects of soak time on the number of fish captured per trap, by
144 including soak time as a covariate in the models testing for effects of habitat on fish
145 relative densities (described below in the results). Soak time always had a negligible
146 effect ($P > 0.05$), so relative densities were not adjusted for variable soak times.
147 Relative density was calculated for each species at each site for each sampling day.
148 Data from 2004 and 2005 were analyzed separately. In 2004, data from the black sea
149 bass pots and O-pots were pooled because we assumed they would sample with similar
150 effectiveness. Fish relative densities were, however, calculated separately by trap type
151 in 2005 to test this assumption explicitly.

152 We used analysis of variance (ANOVA) to test for effects of habitat (a fixed
153 effect), individual sites (a fixed effect nested within habitat), sampling session (a random
154 effect), and interactions between these factors. The primary goal was to compare oyster
155 cage and natural rocky reef habitats. Because there was only one artificial reef site, this
156 habitat was not included in the ANOVAs, but mean relative densities on the artificial reef
157 are presented for comparative purposes. Scup were sufficiently abundant to allow
158 separate analyses of three age-class, defined using established size-age relationships:
159 age-0 (< 99 mm fork length (FL)), age-1 (100 mm –154 mm FL), and age-1+ (>154 mm
160 FL) (Morse 1978; Gray 1991).

161 *Growth and disappearance rates of scup*

162 Of the four study species tagged, only scup were recaptured in great enough
163 numbers to permit calculation of growth and disappearance rates. Individual growth
164 rates were obtained by remeasurement of all tagged scup that were recaptured after
165 being at liberty for more than 4 d. We selected this minimum interval between captures
166 because after 4 d, growth was always greater than measurement error. Growth rates
167 were calculated as percent increase in initial FL per day. We combined data from 2004
168 and 2005 and used analysis of covariance (ANCOVA) to test for differences in growth of
169 scup between oyster cage and natural rocky reef habitats, using individual fish as
170 replicates. ANCOVA models included effects of habitat type and sites (nested within
171 habitat) as fixed categorical variables. Initial FL and relative density were tested as
172 linear covariates. Prior to testing our hypotheses using ANOVA and ANCOVA, we
173 checked that data conformed to model assumptions (Sokal and Rohlf 1995). Following
174 Winer et al. (1991), we used post-hoc pooling procedures to sequentially remove non-
175 significant interactions and nested terms from models.

176 We also used the mark-recapture information on scup to calculate their
177 disappearance rate. These analyses were based on recapture histories, where each
178 tagged scup was recorded as being either recaptured or not for each of the three
179 sampling sessions. A few scup were recaptured at sites outside the study area (see
180 results), indicating that at least some emigration occurred. Recorded instances of
181 emigration were, however, too few to estimate emigration rates. Calculated
182 disappearance rates thus include both emigration and mortality. We fit models
183 commonly used for survival analysis to the data, using the date of tagging as a common

184 start day (Lee 1992). The recapture histories yielded a mix of interval-censored
185 (disappearance between sample sessions) and right-censored (alive at end of study)
186 observations. We fit the simplest exponential model, which assumes a constant
187 instantaneous loss rate because it appeared to fit the data adequately, and only very
188 slight improvements in fit were obtained with more complex Weibull and Cox models.
189 All statistical analyses were done using SYSTAT, version 11.0 (SYSTAT Software, Inc.,
190 Richmond, California).

191 **Results**

192 *Scup relative density, growth and disappearance*

193 Age-1 and older scup were at higher relative densities at oyster cage sites than
194 at natural rocky reefs in both 2004 (age-1 scup ANOVA: $F = 5.629$; $df = 1,52$; $P = 0.021$,
195 age-1+ scup ANOVA: $F = 14.790$; $df = 1,52$; $P < 0.001$) and 2005 (age-1 scup ANOVA:
196 $F = 12.582$; $df = 1,141$; $P < 0.001$, age-1+ scup ANOVA: $F = 22.286$; $df = 1,141$; $P <$
197 0.001) (Figure 2). Age-0 fish, however, showed no consistent pattern, with significantly
198 higher relative densities at natural rocky reefs in 2005 (ANOVA: $F = 4.825$; $df = 1,141$; P
199 $= 0.03$), and no detectable difference among habitats in 2004 (ANOVA: $F = 1.213$; $df =$
200 $1,52$; $P = 0.276$) (Figure 2). The relative density of scup at the artificial reef was neither
201 consistently higher nor lower than at the other two habitats, and generally fell between
202 the two (Figure 2).

203 Of the 735 scup tagged in 2004, 78 were recaptured (10.6%) and of the 632 scup
204 tagged in 2005, 100 were recaptured (15.8%). The higher recapture rate in 2005 may
205 be due to the increased trapping frequency, or because larger fish (>109 mm FL) were
206 tagged in 2005 than in 2004 (>71 mm FL). The ANCOVA model testing effects of

207 habitat type, sites (nested within habitat), initial FL and relative density on scup growth
208 revealed no significant interactions between factors (P always > 0.29), so interaction
209 terms were removed from the model. Small scup did, however grow faster than large
210 scup (ANCOVA: $F = 20.427$; $df = 1,112$; $P < 0.001$; Fig. 2). Growth rates differed
211 among habitats (ANCOVA: $F = 9.745$; $df = 1,112$; $P = 0.002$), but did not differ among
212 the sites within each habitat (ANCOVA: $F = 1.718$; $df = 5,112$; $P = 0.136$). Overall, the
213 mean growth rate of scup at natural rocky reefs was roughly 1.5 times faster ($\bar{x} =$
214 $0.279\%/d$) than that at oyster cages ($\bar{x} = 0.169\%/d$) (Figure 3). Relative density had no
215 detectable effect on growth (ANCOVA: $F = 1.718$; $df = 5,112$; $P = 0.136$), but the test for
216 this effect was confounded with habitat because scup were more abundant at oyster
217 cages than at natural rocky reefs.

218 While trapping at our study sites, no scup was recaptured at a site other than the
219 site at which it was tagged. We thus found no evidence of emigration amongst our
220 study sites. We did, however, verify three records of tagged scup caught elsewhere. In
221 two instances, the fish were caught by anglers about a month after tagging within 10 km
222 of the initial tagging sites. The third scup was caught six months after being tagged by
223 a fishing vessel in Hudson Canyon, approximately 250 km southwest of Narragansett
224 Bay.

225 Most scup recaptures at our study sites occurred less than 16 d after the date of
226 initial capture (91% on natural rocky reefs, 89% on oyster cages, and 83% on the
227 artificial reef). Thirteen scup were recaptured more than 30 d after initial capture, and
228 one was recaptured almost a year later (334 d). In both years, the disappearance rate
229 of scup was lower at oyster cages than on natural rocky reefs. When 2004 and 2005

230 data were pooled, the instantaneous disappearance rate from oyster cage habitats (n =
231 881) was 0.234 and the disappearance rate from natural rocky reefs (n = 253) was
232 0.312. Based on the lack of overlap in the 95% confidence intervals (CI), this roughly
233 25% reduction in disappearance rate from oyster cage habitat was statistically
234 significant (Figure 4). The rate at which scup disappeared from the artificial reefs
235 (0.334, n = 84) was not distinguishable statistically from that at the other two habitats
236 (95% CI = 0.273 - 0.430).

237 *Relative densities of black sea bass, cunner and tautog*

238 In both 2004 and 2005, the relative density of black sea bass increased from July
239 to October (2004 ANOVA: $F = 16.391$; $df = 2,52$; $P < 0.001$, 2005 O-pot ANOVA: $F =$
240 19.084 ; $df = 2,141$; $P < 0.001$, 2005 Minnow trap ANOVA: $F = 17.373$; $df = 2,135$;
241 $P < 0.001$). Relative densities of black sea bass did not, however, show any consistent
242 differences among habitat types (Figure 5). In 2004, all 68 black sea bass caught were
243 age-1 or older (Able and Hales 1997) and relative density showed no obvious
244 differences between natural rocky reefs and oyster cages (ANOVA: $F = 0.337$; $df =$
245 $1,52$; $P = 0.564$). In 2005, however, 542 of the 549 black sea bass caught were age-0.
246 There was a detectable difference in density measured using O-pots in 2005, with more
247 black sea bass at the natural rocky reef sites (ANOVA: $F = 4.477$; $df = 1,141$; $P =$
248 0.036). However, this trend was not apparent in catches from minnow traps in 2005
249 (ANOVA: $F = 0.427$; $df = 1,135$; $P = 0.515$). Relative density at the artificial reef also
250 showed no consistent tendency to be higher or lower than at the other habitats (Figure
251 5).

252 In contrast to black sea bass, cunner did show a consistent habitat-specific
253 pattern of relative density. Cunner were always denser at natural rocky reefs and at the
254 artificial reef, than at oyster cages (Figure 6). The difference in density between natural
255 rocky reefs and oyster cages was statistically significant in 2005 (O-pot ANOVA: $F =$
256 5.929 ; $df = 1,135$; $P = 0.016$; Minnow trap ANOVA: $F = 7.265$; $df = 1,141$; $P = 0.008$),
257 but not in 2004 (ANOVA: $F = 1.261$; $df = 1,52$; $P = 0.267$).

258 Tautog were generally less abundant than the other three study species, and
259 there were no obvious changes in tautog relative density among sample sessions (2004
260 ANOVA: $F = 2.029$; $df = 1,52$; $P = 0.135$, 2005 O-pot ANOVA: $F = 0.59$; $df = 1,141$; $P =$
261 0.556 , 2005 Minnow trap ANOVA: $F = 4.05$; $df = 1,135$; $P = 0.046$). Like cunner, and
262 scup, tautog differed consistently in relative density among habitat types. Tautog were
263 always denser at oyster cages than at natural rocky reefs (Figure 7), but this difference
264 was only statistically significant for minnow trap catches (2004 ANOVA: $F = 3.021$; $df =$
265 $1,52$; $P = 0.088$, 2005 O-pot ANOVA: $F = 2.502$; $df = 1,141$; $P = 0.116$, 2005 Minnow
266 trap ANOVA: $F = 4.05$; $df = 1,135$; $P = 0.046$). Although the artificial reef was not
267 compared to the other habitats statistically, it appears that tautog were denser at the
268 artificial reef than at either oyster cages or natural rocky reefs (Figure 7).

269 **Discussion**

270 *Do fish traps accurately measure relative density?*

271 All methods of estimating fish density in the field have potential biases (Rozas
272 and Minello 1997). We used fish traps because all of our study species are known to
273 readily enter traps (e.g. Able and Hales 1997; Able et al. 2005), and the three
274 commercially valuable species are harvested using traps (Eklund and Targett 1991).

275 Our primary concern in this study is not bias in the absolute catch rate of traps, but that
276 relative catch rates among habitats accurately reflect relative differences in fish density.
277 One step we took to reduce possible trap bias was to use multiple trap types. The fact
278 that three different trap types yielded the same patterns of captures across habitats
279 eliminates the possibility of bias unique to any one trap type. Nonetheless, we cannot
280 rule-out the possibility that all three trap types sampled more efficiently in one habitat
281 than another. One way to assess any bias common to all three trap types would be to
282 directly observe fish interacting with traps in each habitat (e.g. Able et al. 2005), but
283 poor underwater visibility thwarted most of our attempts at this. We also considered
284 comparing trap-based density estimates with estimates from an alternate method (e.g.
285 Layman and Smith 2001; Edgar et al. 2004). Unfortunately, the most promising
286 alternate methods for our study species, seining, trawling, and visual census using
287 SCUBA, were not usable at our sites because the habitat interferes with nets and
288 underwater visibility is low.

289 *Are oyster grow-out cages equivalent to natural and artificial reefs?*

290 In this study, we assessed a poorly studied, environmental effect of oyster grow-
291 out cages - their value as habitat for reef-associated fishes. Assessing the value of
292 artificial habitats requires explicit comparison of the artificial and natural habitat (Carr
293 and Hixon 1997). Interestingly, the relative density of our four study species showed no
294 consistent pattern of difference among the oyster cages and natural rocky reefs. Both
295 tautog and scup (age-1 and older) were at least three times denser on the oyster cages
296 than on natural rocky reefs, whereas cunner were roughly three times more dense on
297 natural rocky reefs. Black sea bass, however, showed no discernible difference in

298 density among habitats. For scup, the only species abundant enough to analyze by
299 age-class, their preference for different habitats was age-specific. Although age-1 and
300 older scup were denser on oyster cages than natural rocky reefs, age-0 scup showed
301 no consistent difference. Clearly, then, although oyster cages provide suitable habitat
302 for reef-associated fishes, they will support a finfish community quantitatively different in
303 composition from that on natural rocky reefs. The same is true, however, of most
304 artificial reefs deliberately constructed to mimic natural habitat (Seaman and Sprague
305 1991; Pratt 1994). In our study, for example, Tautog showed a strong preference for
306 the granite artificial reef over either the natural rocky reefs or the oyster cages.

307 *Do oyster grow-out cages increase regional fish abundance?*

308 The most controversial, and difficult to assess, putative benefit of artificial reefs is
309 whether they can increase regional fish abundance (Bohnsack 1989; Pickering and
310 Whitmarsh 1997; Osenberg et al. 2002). The regional benefit of artificial reefs depends
311 on (1) the amounts of natural and artificial habitats, (2) the extent to which artificial reefs
312 redistribute individuals that would otherwise recruit to natural habitats, and (3) the
313 strength of density dependent growth and survival in each habitat afterwards (Osenberg
314 et al. 2002). No studies have addressed this issue unambiguously (Osenberg et al.
315 2002), and ours is no exception.

316 The species we studied occupy natural reefs of rock/cobble and biogenic
317 materials (e.g. oysters, mussels, coral, and tube worms). They also occupy a variety of
318 hard, three dimensional man-made structures (e.g. jetties, submerged pipelines and
319 cables, shipwrecks and debris). It is difficult to precisely estimate the coverage of these
320 natural and artificial reef habitats in Narragansett Bay (McMaster 1960; Poppe 2003;

321 Tiner et al. 2004) and in the Mid-Atlantic Bight generally (Steimle and Zetlin 2000;
322 Stevenson et al. 2004). It is clear, however, that natural reefs are relatively rare in the
323 region compared to soft sediments, and that natural oyster reefs in particular have
324 declined dramatically over the past 100 years. Man-made structures, whether
325 purposely or inadvertently deployed as reefs, are also rare but have increased in
326 abundance over the past 100 years. The culture of oysters in grow-out cages is
327 increasing in many parts of the US. The area covered by oyster grow-out cages in
328 Rhode Island, for example, has been growing by 30% per year over the past 10 years
329 and in 2005, grow-out cages at 25 leased sites covered 35 hectares of previously soft-
330 sediment habitat.

331 Given the paucity of natural reef habitat in Narragansett Bay, it seems unlikely
332 that all of the fishes recruiting to oyster cages would simply have colonized nearby
333 natural rocky reefs had the oyster cages been absent. If that supposition is correct, the
334 growth and disappearance rates of scup on the oyster cages can provide a rough
335 indication of the potential enhancement of production attributable to oyster cages
336 (Peterson et al. 2003). Interestingly, scup on oyster cages disappeared at a lower rate
337 than scup on natural rocky reefs (by roughly 25%), indicating that some combination of
338 mortality and/or emigration is reduced on oyster cages. This indication of better habitat
339 quality on oyster cages was, however, offset by reduced growth rates at the aquaculture
340 sites (by roughly 40%). The net consequence of these countervailing patterns of loss
341 and growth is not certain, but they are relatively subtle in magnitude compared to the
342 more than three-fold increase in scup density on oyster cages. Consequently, scup

343 production measured on a per-unit-area basis is almost certainly higher on oyster cages
344 than on natural rocky reefs.

345 An important aspect of the aquaculture process that may affect the ultimate
346 habitat value of grow-out cages is the protocol for cage maintenance and harvesting of
347 oysters. Juvenile finfish might be trapped in the cages, or simply displaced by the
348 removal of their habitat, when cages are pulled from the water for cleaning or harvest
349 (O'Beirn et al. 2004). Aquaculture methods typically used in Rhode Island should
350 however, minimize these sources of finfish mortality. Harvesting and maintenance
351 usually occurs only two to four times a year, and cages are dragged through the water
352 before being hauled above the surface to reduce by-catch. Because only a few cages
353 are hauled up at one time, and returned to the water quickly, displaced finfish and
354 invertebrates are likely to be able to seek refuge in other nearby cages. Evidence
355 suggesting that most finfish do indeed escape is the fact that Kilpatrick (2002)
356 recovered hundreds of juvenile fish when he enclosed grow-out cages in fine-meshed
357 nets prior to removal from the water. In contrast, hauls of un-netted cages typically
358 bring up only a handful of fish (R. Rheault, Moonstone Oysters, personal
359 communication). Encouraging practices that minimize the impacts of harvesting and
360 maintenance will be important in order to fully realize the benefits of grow-out cages as
361 quality finfish habitat. With that caveat in mind, our results suggest that oyster grow-out
362 cages do provide valuable habitat for finfishes and should be considered alongside
363 other artificial reef designs as part of habitat restoration programs.

364 *Do oyster-grow out cages provide habitat similar to natural oyster reefs?*

365 The loss of natural oyster reefs has spurred much recent interest in restoring this
366 habitat and the ecological services it provides (Ulanowicz and Tuttle 1992; Coen et al.
367 1999; Luckenbach et al. 1999). We did not compare grow-out cages to natural oyster
368 reefs, simply because suitable oyster reefs are not present in Narragansett Bay. All of
369 our study species have, however, been reported on natural oyster reefs in the Mid-
370 Atlantic Bight (Steimle and Zetlin 2000; Peterson et al. 2003). It is thus possible that
371 grow-out cages can provide habitat for reef-associated fishes that is similar to that
372 provided by natural oyster reefs. Future research testing this hypothesis explicitly would
373 be extremely informative.

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535 **Figure captions**

536 Figure 1. Map of the study sites indicating which sites were studied in 2004 only, 2005
537 only, or in both years.

538 Figure 2. Mean (\pm SE) relative density of scup in three habitat types. Only one artificial
539 reef was sampled, so this datum has no SE and is displayed as a point rather than a
540 bar. Separate plots are drawn for three age classes: age-0, age-1, and age-1+.

541 Figure 3. Mean (\pm SE) growth rates of age-1 and age-2 scup on natural rocky reefs and
542 aquaculture sites.

543 Figure 4. An exponential model for disappearance rates (mortality and emigration) of
544 scup on natural rocky reefs and aquaculture sites. Dotted lines represent 95%
545 confidence intervals.

546 Figure 5. Mean (\pm SE) relative density of black sea bass in three habitat types. Only
547 one artificial reef was sampled, so this datum has no SE and is displayed as a point
548 rather than a bar.

549 Figure 6. Mean (\pm SE) relative density of cunner in three habitat types. Only one
550 artificial reef was sampled, so this datum has no SE and is displayed as a point rather
551 than a bar.

552 Figure 7. Mean (\pm SE) relative density of tautog in three habitat types. Only one
553 artificial reef was sampled, so this datum has no SE and is displayed as a point rather
554 than a bar.

Figure 1

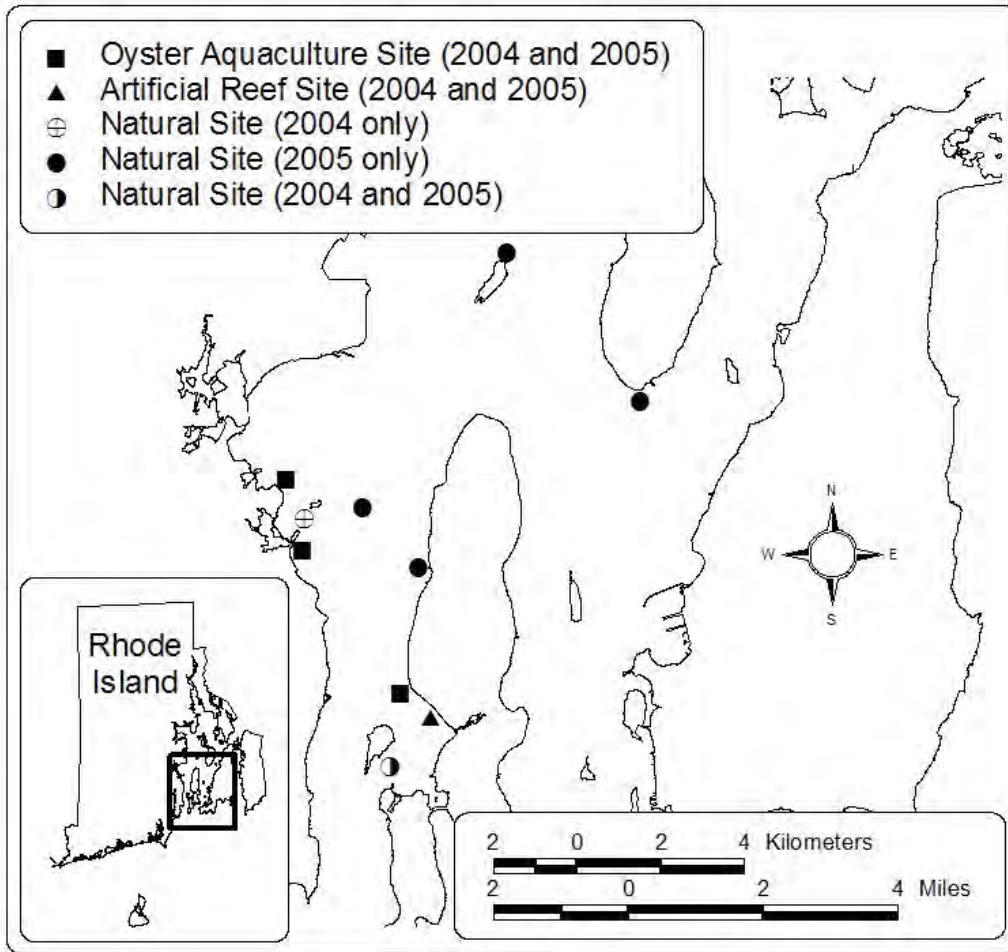


Figure 2

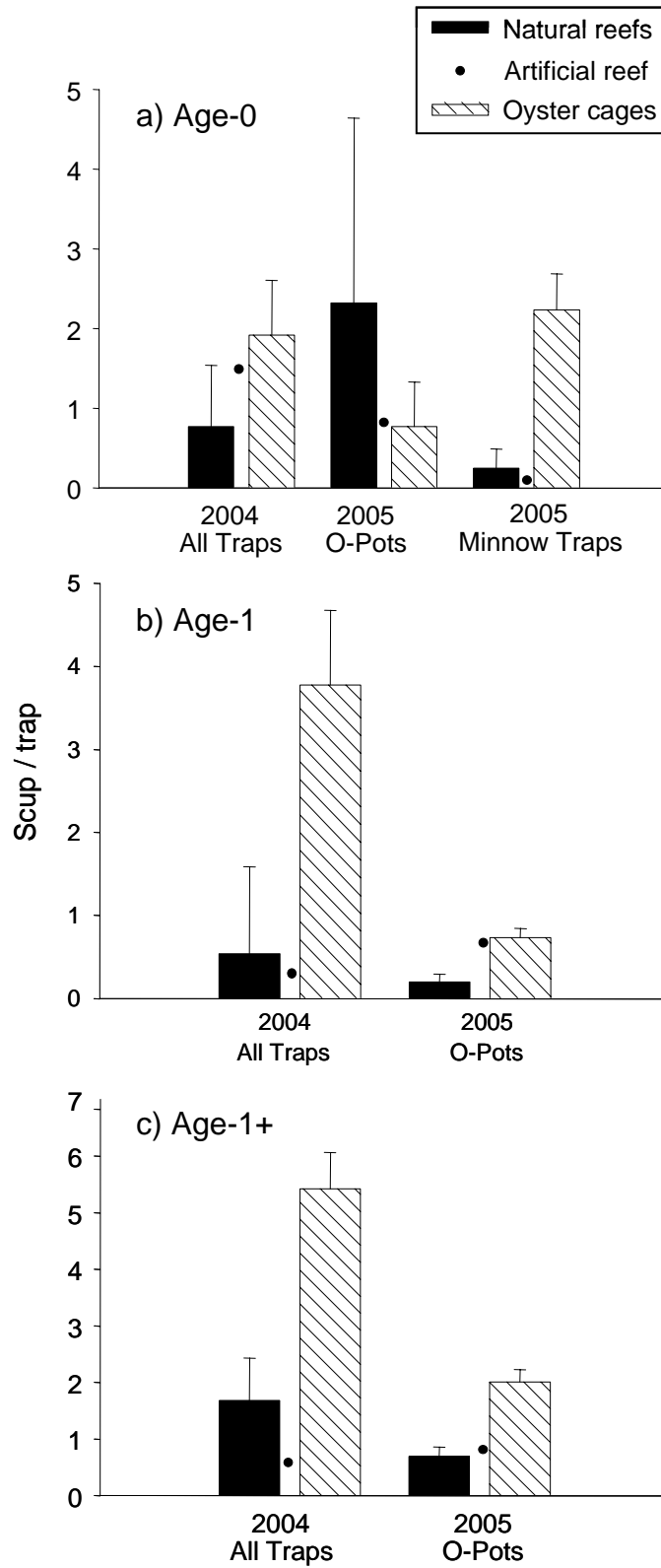


Figure 3

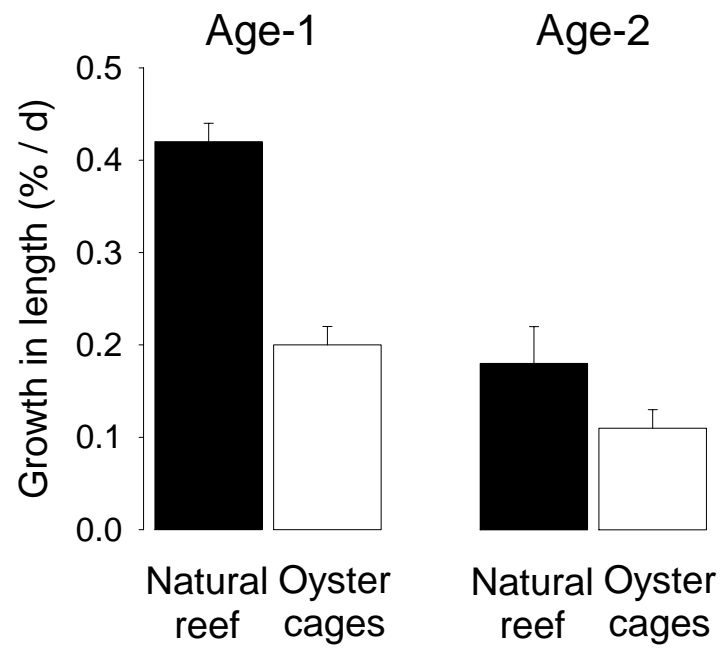


Figure 4

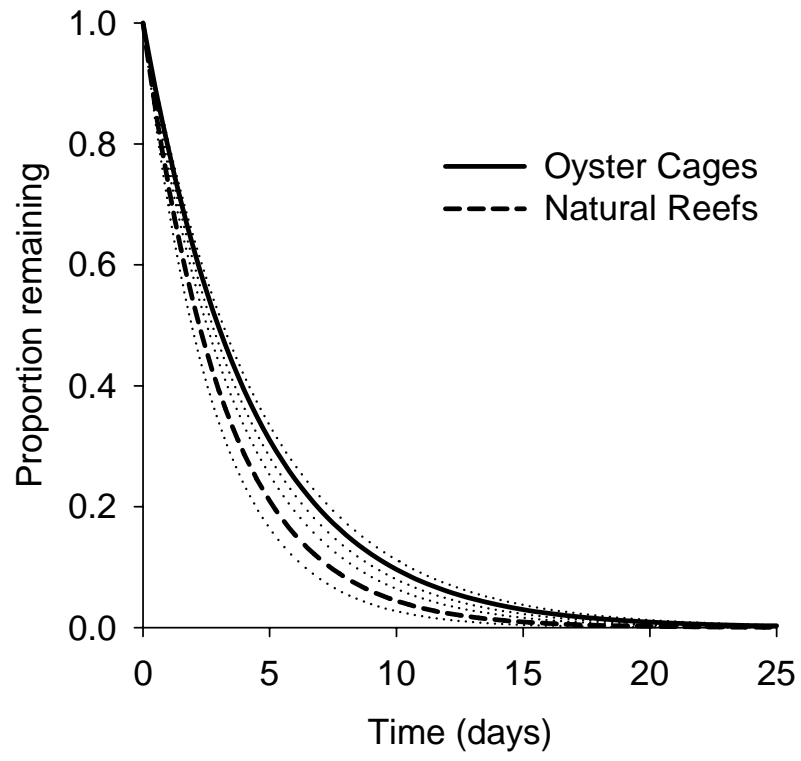


Figure 5

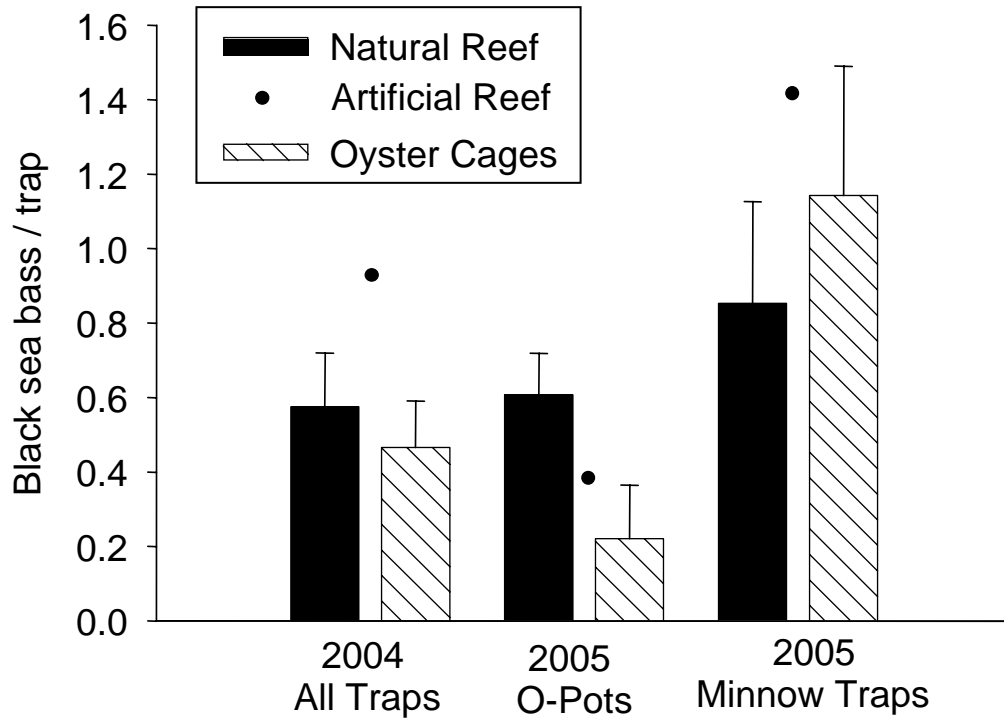


Figure 6

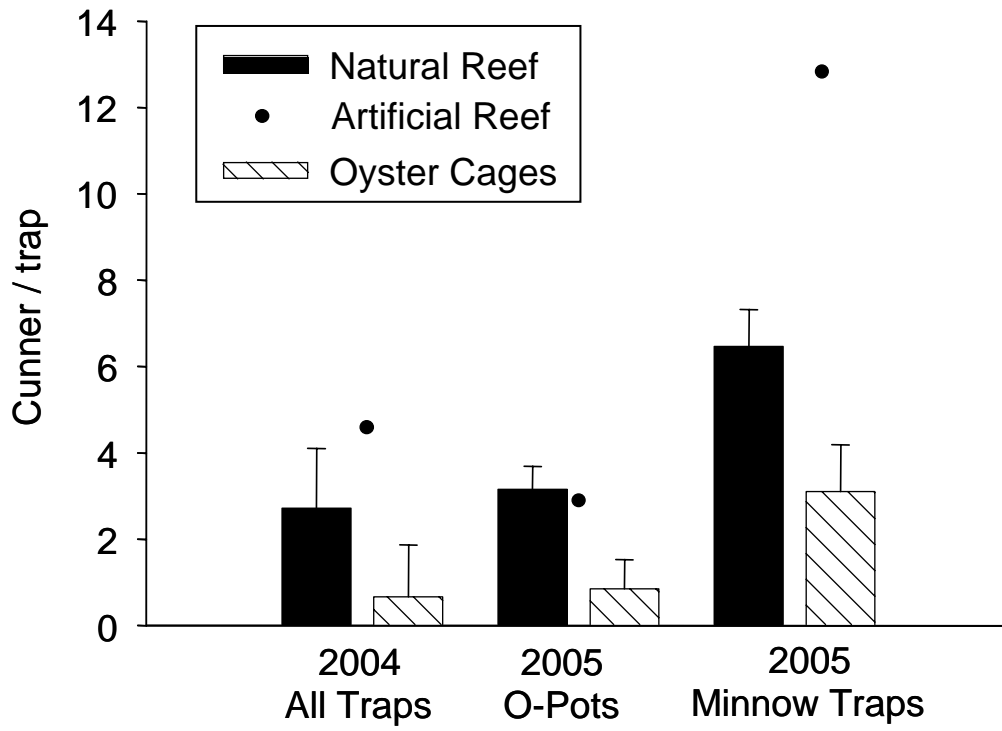


Figure 7

