In the 1979–1988 water budget (Fig. 1c), which is representative of current conditions, evapotranspiration (541 mm/y) and streamflow (538 mm/y) each account for about 45% of precipitation (1180 mm/y). Diversions leaving the basin (143 mm/y) are greater than diversions entering the basin (33 mm/y). The change in storage (−9 mm/y) is small. However, in this study, we ignored the absolute value of the storage component because it is highly dependent on the evapotranspiration estimate, which is the least accurate component of any large-scale water budget; only the temporal variation is considered. During the summer months (Fig. 1d), the change in storage is most negative, due to increasing evapotranspiration, and it is coincident with decreasing rainfall and streamflow. Diversions remain relatively constant throughout the year, with high groundwater pumping during the summer balanced by surface water withdrawals into reservoirs during the rest of the year. The effect of diversions should be most apparent during the summer months because streamflow is lowest at this time.

With increasing water demands, diversions have become a major component of the water budget—they currently represent 15%–20% of the streamflow. Our analyses of the water budget did not reveal any significant long-term trend in change in storage or in streamflow. This suggests that to understand the impact of diversions on the system we ought to reduce the time step (to daily or hourly) to examine changes in streamflow; focus the study area on the upper Ipswich basin where low flows occur and the river dries up most frequently; and look at different indices of hydrological change, such as the number of days of low flow and groundwater levels. Low streamflow is detrimental not only to the river ecosystems, but also to the downstream estuary, where alterations in salinity during the summer months could increase the stress on estuarine communities, a topic that requires further research.

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Population Size and Summer Home Range of the Green Crab, *Carcinus maenas*, in Salt Marsh Tidal Creeks

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The green crab, *Carcinus maenas*, is native to the Atlantic coast of Europe. First reported in the western Atlantic in 1817, it is abundant today in salt marshes and on rocky shores from Nova Scotia to Virginia. As a predator, it has been linked to the sharp decline of the New England soft-shell clam (*Mya arenaria*) industry in the 1940s (1). Since the crab was first found in San Francisco Bay in 1989, scientists and fishers have been anxiously monitoring its movement northward and its effects on the ecosystem (2). Despite interest in the extension of the species' geographic distribution, little work has been conducted on the home range of individual crabs. We examined the population size and summer home range of green crabs in a New England salt marsh tidal creek.

We conducted a mark-recapture experiment in a branched primary tidal creek off of the Rowley River in the Plum Island Sound Estuary in northeastern Massachusetts. The upper 200 m of the creek has about 7274 m^3 of volume and about 7128 m^2 of creek bed area. Water temperature (16°–25°C) and salinity (28‰–31‰) in the creek were typical of New England salt marshes in late spring and summer. From 29 June to 6 August 1999, crawfish traps (20 × 30 × 45 cm with 1.3-cm mesh and 8-cm opening) baited with tuna fish or dog food soaked in fish oil were laid along both branches and downstream of the confluence at seven sites 100 m apart. From 29 June to 30 July, each trapped crab measuring 40 mm or more was marked either with colored oil-based marker paint on the carapace or with a plastic loop behind the claws. The carapace width (in millimeters), sex (male or female), and carapace color (red or green) of each crab were also noted. Crabs trapped at each of the seven sites were marked with a distinct color scheme and then released at the same site. Marked crabs that were recaptured were marked a second time with the color scheme corresponding to their recapture location. Crabs trapped from 3 to 6 August were counted and removed from the creek. We used the Lincoln index and the Schnabel method to estimate population size (3). We also conducted two catch-per-unit-effort collections in five other similar-sized primary tidal creeks off of the Rowley River (Sand Creek, Shad Creek, West Creek, Club Head Creek, and Nelson Island Creek) by deploying traps from high tide to low tide (~6 h).

We estimated the population of green crabs in the study creek to be 30,000–40,000 individuals (~5 crabs per m^2) (Table I). Recapture rate of marked crabs was between 5% and 11%. The average number of crabs caught over a 6-h period did not differ significantly between the study creek and the other five creeks

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Table I

Estimates of the population size of green crabs, Carcinus maenas, *in a tidal creek in Rowley, Massachusetts*

Marking technique	Marking period	Number of crabs marked	recaptured	captured	Recapture rate	Estimated population	95% confidence interval
Paint[1]	29 June–1 July	87	9	4095	10.35%	39585	23852–118948
Plastic tags[1]	12 July–16 July	240	25	3735	10.42%	35856	25636–59627
Paint[2]	26 July–30 July	1887	109	1848	5.78%	31992	26979–39295
All marking techniques[2]	29 June–30 July	2378	120	1848	5.05%	36621	31126–44473
All marking techniques[3]	29 June–30 July	2629	145	4251	5.52%	32746	28082–39268

[1] Estimates calculated using the Lincoln index, counting all crabs trapped in subsequent weeks as the single capture sample (6). The number of marked crabs used in these calculations was 66% of the actual number marked because approximately 33% of marked crabs in the laboratory lost their marks in two weeks.

[2] Estimates calculated using the Lincoln index with the collection from 3 to 6 August as the single recapture sample (6).

[3] Estimate calculated using the Schnabel method, treating each marking technique as one of the repeated recapture samples (6).

sampled. We caught slightly more male crabs (n = 1257) than female crabs (n = 1131), but the numbers were not significantly different (P = 0.32, t = 1.03, d.f. = 16). We caught five times as many green-colored crabs (n = 1921) as red-colored crabs (n = 364) (P = 0.0004, t = 4.73, d.f. = 13). As is typical of this species (4), males were larger than females in our collections ($P < 0.0001$, t = 21.447, d.f. = 2386). Red-colored males (mean = 56 ± 0.593 SE) were larger than green-colored males (mean = 52 ± 0.193 SE; $P < 0.0001$, t = 5.75, d.f. = 1187), and red-colored females (mean = 48 ± 0.269 SE) were also larger than green-colored females (mean = 47 ± 0.165 SE; P = 0.0006, t = 3.43, d.f. = 1094). We found no significant difference in average crab size between the beginning (mean = 49 ± 1.073 SE) and the end (mean = 49 ± 0.215 SE) of the study period. This stability in crab size over time suggests that we did not lose many marks to molting.

About half of the 149 recaptured crabs were trapped at the same site both times (Fig. 1). As the distance from the marking site increased, the number of recaptured crabs decreased: only 5% of the crabs were recaptured 300–400 m upstream or downstream from their original marking site (the extent of the trapping area). There was no significant difference between the numbers of crabs found upstream and those found downstream (P = 0.37, t = 0.97, d.f. = 6). Three percent crossed from one branch of the creek to the other, either through the mosquito ditch network connecting the two branches (about 150 m of travel), or down to the confluence and back up the other branch (about 300 m).

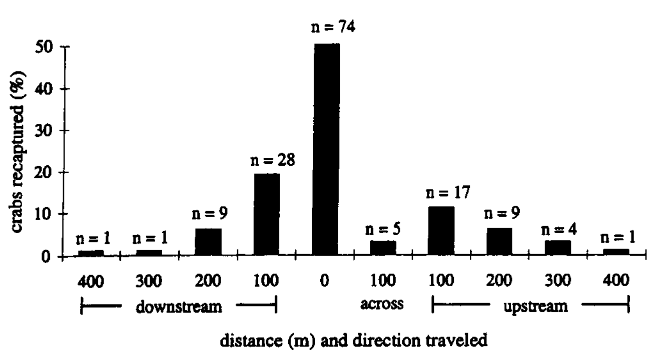

Figure 1. *Distance and direction (upstream, downstream, or across) traveled by recaptured green crabs,* Carcinus maenas, *in a tidal creek in Rowley, Massachusetts.*

Our population density estimate of 5 crabs per m^2 is comparable to previous estimates for green crabs on rocky shores in Wales (4). The results of the catch-per-unit-effort comparison for the six creeks suggest that this value may be a good estimate of green crab populations in the Rowley River.

Green-colored crabs are found throughout the molt cycle, but some crabs become red-colored during prolonged intermolt stages (5, 6). Green-colored crabs are more tolerant of low salinities than are red-colored crabs (6): the green form has been found primarily in the intertidal zone on Welsh shores and the red form primarily in the subtidal zone (7, 8). The dominance of green-colored crabs in our collection may be a result of the large tidal range (>3 m) and narrow subtidal zone in the study creek. McGaw (5) found red-colored males to be larger than green-colored males and hypothesized that this color change may be partly associated with sexual maturity.

The recapture data suggest that green crabs can move at least 400 m upstream or downstream, but that for the most part they remain within a 400-m range during the summer. Frequency of distance traveled was calculated only from crabs recaptured 1 to 3 weeks after each marking period in order to allow marked crabs to remix with the general population of the creek. But we also recaptured several crabs 300–400 m away from their original marking site within 4 days of being marked, indicating that they can move at least 400 m in a matter of days; distance traveled may thus not be directly related to time.

A study of the movement of crabs within the creeks in relation to tidal cycles would expand on previous research showing that these crabs follow tides up and down rocky shorelines in Wales (4, 7, 8). Warman (7) and Crothers (4) suggest that green crabs move offshore in the winter; an investigation of the winter range of green crabs would also add to information on the annual range of individual green crabs. Such research would contribute to the understanding of the role of this invasive species in coastal ecosystems.

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Influence of Marsh Flooding on the Abundance and Growth of *Fundulus heteroclitus* in Salt Marsh Creeks

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Like many other estuarine fish and crustaceans, *Fundulus heteroclitus* (mummichog) regularly makes use of the marsh as a foraging area, nursery habitat, and refuge from predators. Mummichogs are known to follow flooding tides onto the intertidal marsh to forage (1, 2). Through this behavior, they provide an important trophic link between salt marsh and open estuary (3). Previous research indicates that access to the intertidal flooded marsh has significant effects on the growth rate of *F. heteroclitus.* Weisberg and Lotrich (4) showed that foraging exclusively on subtidal food sources was not sufficient to support normal growth rates of mummichogs. Javonillo *et al.* (5) found that mummichogs denied access to the marsh had lower growth rates than those that were allowed entrée to the marsh surface. Both of these studies employed caging techniques on a relatively small scale. Our goal was to examine the importance of marsh flooding to mummichog growth and abundance in a natural environment without enclosures.

Tidal creek flooding onto the marsh determines the vegetation in the area surrounding the creek. *Spartina alterniflora* grows on the marsh adjacent to the creek that floods on every high tide, whereas *S. patens* grows on the higher marsh that floods less frequently. We measured the length from the creek edge to the transition between *S. alterniflora* and *S. patens* at increments along the creek. The mean of these measurements multiplied by the length of the creek was considered the area of marsh accessible to mummichogs at high tides. This area is equivalent to the area of marsh adjacent to the creek covered by *S. alterniflora.* A comparison of the regularly flooded area in the 5 tidal creeks that were part of our study is shown in Figure 1a.

We measured the abundance and growth of *F. heteroclitus* in tidal salt marsh creeks of the Rowley River in the Plum Island Estuary in northeastern Massachusetts (42°44′ N × 70°50′ W). Over 6 weeks, catch-per-unit-effort (CPUE) was measured three times in each of five salt marsh creeks. Ten minnow traps (6.35-mm mesh), spaced evenly in the primary tidal creeks, were set at high tide and retrieved about 5 h later during low tide. In two of the creeks, we measured growth of mummichog young-of-the-year, the life stage in which the most dramatic growth occurs. Four times during the 6 weeks (first three times coincided with CPUE measurements, plus one additional growth measurement), the total lengths of between 275 and 1000 fish from each creek were measured, and length-frequency histograms were constructed. Probability paper was used, according to the method described by Harding (6), to identify the young-of-the-year cohort from the length-frequency histograms. Mean values from each set of measurements were plotted to evaluate growth.

Catch-per-unit-effort measurements indicated that mummichogs tended to be more abundant in creeks with greater areas of frequently flooded marsh (correlation coefficient = 0.83, P = 0.09) (Fig. 1b). This relationship suggests that creeks with increased marsh flooding are able to support a larger population of mummichogs by providing greater regularly flooded areas for foraging, or that creeks with increased flooding offer greater refuge from predation. Mummichogs that follow the high tide onto the marsh surface become more exposed to predation by shorebirds, but they gain protection from predation by larger fish, the more likely predator. Although the creeks are very similar, properties other than regularly flooded area—including dimensions, water volume, temperature regime, productivity, and food availability—may affect the abundance of mummichogs in a creek.

The pattern of growth was the same for young-of-the-year mummichogs in Sweeney Creek and Club Head Creek (Fig. 1c). However, the mean total length values of mummichogs from Sweeney Creek were significantly greater than mean total length measurements from Club Head Creek (Complete Randomized Block ANOVA $P < 0.05$). Though statistically significant, the very small mean difference between measurements of 1.25 mm is unlikely to be of ecological significance, especially since the pattern of growth did not differ between the creeks. Unlike in

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