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Short-term changes in tidepools following two hurricanes

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Abstract

Three tidepools in the rocky intertidal zone of coastal Maine, USA, were examined before and after the passing of two hurricanes: Gloria, in 1985, and Bob, in 1991. Surface area was little changed in one pool, and reduced in a second pool that were formed from rock. Surface area increased significantly in a third pool that had a nonpermanent border. Sand deposition on the bottom of tidepools increased in three of the five pairs of observations, and sand was not present before or after storms in the other two instances. Algal cover was generally reduced, and beds of blue mussel (*Mytilus edulis*) were significantly reduced or were extirpated. Fish numbers were generally lower after the storms, but numbers returned to pre-event levels in the following season. Physical and biological alterations to tidepools were often severe for the short term, but systems were resilient for the long term.

Introduction

There have been periodic reports of damage to freshwater and marine environments following hurricanes and other major storms. Most reported alterations have involved physical processes, such as redistribution of flotsam (Bishop, 1981), or sediment deposition or scouring in inlet-barrier beach locales (Webb et al., 1989), coastal marshes (Rejmanek et al., 1988), coral reefs (Letourneur et al., 1993), or estuarine areas (Rao, 1981). However, some biological consequences of major storm action have also been noted. Inshore, subtidal fishes have been killed by excessive wave action or high siltation (Creaser, 1942; Robins, 1957; Tabb & Jones, 1962; Follett, 1970; Bodkin et al., 1987). In general, fishes are affected most by habitat alterations (Kaufman, 1983; Fenner, 1991). Mortalities of juvenile coral reef fishes have been linked to hurricanes (Beecher, 1973; Walsh, 1980; Lassig 1983), but the impacts have largely been minor, except in quite shallow areas (Fenner, 1991). Mortalities of freshwater fishes and invertebrates have often been linked to hurricane-induced flooding (Creaser, 1942; Hubbs, 1962; Hoopes, 1975; Willig & Camilo, 1991) and the scouring of sediment (Smock et al., 1994).

Generally, deeper water communities are less affected by hurricanes (Brown & Howard, 1985; Kirby-Smith & Ustach, 1986), but the biological consequences of these extreme conditions can be particularly devastating at the land-sea margin. Andrews (1973) and Yeo and Risk (1979) reported heavy damage to invertebrates in estuarine and intertidal zones.

It has long been assumed that temperate, rocky intertidal communities are affected more by physical conditions than by biological influences (Sanders, 1969), but the evidence is unclear. Menge (1976) concluded that biological influences are often significant, while Dethier (1984) concluded that 'Disturbance is thus the major stochastic process that generates variability' in the intertidal system. While intertidal communities in temperate and boreal areas can often adjust to normal physical disturbances, and recover (Thomson & Lehner, 1976), catastrophic events can be important either negatively, by disrupting ecosystems, or positively, by promoting subsequent biodiversity by reducing dominant species.

Rocky intertidal areas of northern New England are fragile environments where species diversity and biological processes are strongly influenced by physical parameters. During a long-term study, I had the opportunity to examine the fish communities of three tidepools of coastal Maine, USA, and the physical changes to pools brought about by two hurricanes, Gloria, in 1985, and Bob, in 1991. During 201 sampling trips to these pools over 16 years, physical damage as a result of normal storms was obvious on only 4% of the trips, and physical features were re-established within one month. Hurricanes, however, are rare events. The objective of this study was to assess the short-term abiotic and biotic consequences of these potentially catastrophic events to tidepools and their intertidal fish communities.

Materials and methods

Three tidepools and their fish biota along Schoodic Peninsula, near Winter Harbor, Maine, USA, have been examined each year since 1979, normally between April and November, but occasionally in winter as well. Pool A, located on the eastern side of the Peninsula (Figure 1) has an average maximum depth of 53 cm. Direct wave action is from the east, but the pool is effectively protected, being 20 m from open water. Pool B, the smallest of the pools, has an average maximum depth of 37 cm. Direct wave action is from the southwest, and the pool is formed only during minus (<0.0 m) tides. A rock wall forms the eastern boundary of the pool in the lower intertidal zone. Pool C is the largest of the three tidepools, in terms of surface area, but it has an average maximum depth of only 36 cm. Direct wave action is from the west and pool isolation is less than two hours during minus ebb tides. Pools A and B are formed from rock, and their boundaries would not be expected to be significantly altered under normal tidal cycles or routine winter storms. Pool C, however, is formed in the lower low intertidal zone in a sand-bottomed area with scattered boulders, beds of the anthophyte, *Zostera marina*, and small clusters of the blue mussel, *Mytilus edulis*.

The brown algae, *Ascophyllum nodosum* and *Fucus vesiculosus*, ring much of Pool A and parts of pools B and C, although inventories in July 1986 identified *Zostera marina* and 13 species of algae in Pool A, 11 species of marine algae in Pool B, and *Zostera marina* and 14 species of algae in Pool C (Moring, 1989).

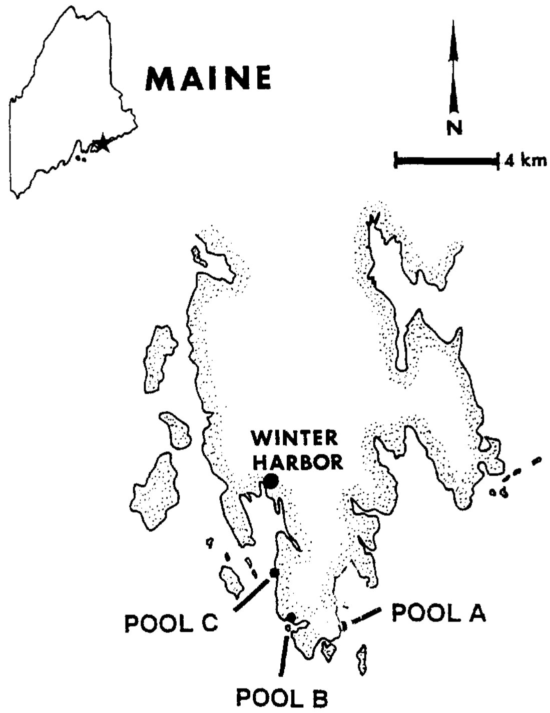

Figure 1. Location of three tidepools (A, B, and C) studied along Schoodic Peninsula, Maine, USA, before and after hurricanes in 1985 and 1991.

Periodically since 1979, the three pools were measured and mapped to identify physical changes between years. Such measurements occurred prior to the passage of the two hurricanes. By making similar measurements soon after each hurricane, short-term structural and biological changes could be detected.

Tidepools were measured using tapes and digital range finders (Sonin, model 60), accurate to the nearest cm, to mark distances, with a compass to record angles. The resultant data were plotted on polar coordinate paper, and the circumference and tidepool surface area determined using a compensating polar planimeter (Keuffel and Esser, model 62-0000). Proportions of tidepools containing algal cover, sand bottom, or mussel beds were estimated by mapping those structures on tidepool maps, and using a polar planimeter to compare the appropriate area of such features to the total pool area.

Micro-features of pools are irregular, thus estimates are subject to some potential measurement errors, however careful the techniques. As a consequence, changes of less than 10% were considered within the possible range of measurement error and were not considered

Table 1. Abiotic and biotic characteristics of Pool A (east exposure), Schoodic Peninsula, Maine, USA, following Hurricane Gloria, 27 September 1985 and Hurricane Bob, 19-20 August 1991.

	Survey dates	
Hurricane Gloria:	3 Sep. 1985	30 Sep. 1985
Tidepool surface area (m^2)	76.9	50.5
Circumference (m)	31.1	25.2
Maximum depth (cm)	55	62
Tidal height (m)	0.1	0.0
Water temperature (° C)	12.8	13.6
Time	—	1705
Number of fishes	15	3
Number of fish species	3	1
Mussel beds (% of total surface)	17	5
Algal cover (% of total surface)[a]	17	8
Hurricane Bob:	16 July 1991	28 August 1991
Tidepool surface area (m^2)	72.4	70.5
Circumference (m)	30.1	29.8
Maximum depth (cm)	52	48.5
Tidal height (m)	0.2	0.1
Water temperature (° C)	16.1	13.3
Time	1430	0750
Number of fishes	5	22
Number of fish species	3	3
Mussel beds (% of total surface)	7	0
Algal cover (% of total surface)[a]	36	8
Sand (% of total bottom)	0	52

[a] At any depth.

Table 2. Abiotic and biotic conditions in Pool B (southern exposure, protected), Schoodic Peninsula, Maine, USA, following Hurricane Gloria, 27 September 1985.

	Survey dates	
	3 Sep. 1985	30 Sep. 1985
Total surface area (m^2)	17.0	16.4
Circumference (m)	14.6	14.3
Maximum depth (cm)	37	48
Tidal height (m)	0.1	0.0
Water temperature (° C)	12.8	15.0
Time	—	1841
Number of fishes	0	0
Number of fish species	0	0
Algal cover (% of surface area)[a]	8	13

[a] At any depth.

Table 3. Abiotic and biotic changes in Pool C (western exposure), Schoodic Peninsula, Maine, USA, following Hurricane Gloria, 27 September 1985, and Hurricane Bob, 19-20 August 1991.

	Survey dates	
Hurricane Gloria:	3 Sep. 1985	30 Sep. 1985
Total surface area (m^2)	104.5	133.6
Circumference (m)	36.2	41.0
Maximum depth (cm)	34	30
Tidal height (m)	0.1	0.0
Water temperature (° C)	13.3	14.4
Time	—	1759
Number of fishes	23	6
Number of fish species	4	3
Zostera marina beds[a]	34	34
Sand (% of total bottom)	16	37
Hurricane Bob:	16 July 1991	28 August 1991
Total surface area (m^2)	120.4	141.1
Circumference (m)	38.9	42.1
Maximum depth (cm)	21	32
Tidal height (m)	−0.2	0.1
Water temperature (° C)	17.8	15.6
Time	0845	0645
Number of fishes	32	19
Number of fish species	1	3
Zostera marina beds[a]	38	15
Sand (% of total bottom)	66	85

[a] Percent of total surface area.

significant. Changes exceeding 10% would not have been due simply to measurement error.

Hurricane Gloria blew across the study tidepools on 27 September 1985. Winds gusted to 138 km/hr as the storm passed across the coast. The three tidepools had been surveyed on 3 September and were re-surveyed 72 hours after the initial effects of the storm, on 30 September. Hurricane Bob passed across the study tidepools on the night of 19–20 August, 1991. Winds gusted to 150 km/hr at the site, with sustained winds of 80 to 97 km/hr. The three tidepools had been surveyed on 16 July and two of them (pools A and C) were re-surveyed 8 days after the hurricane, on 28 August. Pool B was not examined following this second hurricane.

Results

Pool A

Pool A, along the eastern shore, formed from a large depression in rock, was reduced in surface area by

34% following Hurricane Gloria (Table 1), more than could be explained by measuring error. Rocks, sand, and flotsam reduced surface area around the edges of this pool. The bottom was littered with broken shells, primarily blue mussel. Mussel beds were reduced to 29% of their former area within the pool prior to the hurricane, and algae was reduced to 47% of the former coverage (algal presence at some vertical point in a pool).

Although *Fucus vesiculosus* and *Ascophyllum nodosum*, which largely ring the tidepool, appeared unchanged following Gloria, in-pool algae was dramatically reduced, particularly *Laminaria* spp. Nonsessile invertebrates were conspicuous in their absence, with the exception of large size amphipods, *Gammarus oceanicus*. Smaller Amphipoda were not encountered.

Three underyearling lumpfish, *Cyclopterus lumpus* (23, 28, and 31 mm TL) were encountered attached to *Ascophyllum nodosum* and *Laminaria digitata*, but no other fishes were collected. During the sampling trip prior to Hurricane Gloria, 11 lumpfish (10–21 mm), 2 shorthorn sculpin, *Myoxocephalus scorpius* (137, 162 mm), and 2 grubby, *M. aeneus* (50, 52 mm) were collected. The hurricane struck during the warmest time of the year and the month of highest fish species richness, based on collections made from 1979 to 1988 (Moring, 1990). Fish collections made in the same time period in 1984 were 23 lumpfish, 1 shorthorn sculpin, and 1 Atlantic seasnail, *Liparis atlanticus*. Following Hurricane Bob, total surface area of the tidepool decreased slightly (3%), a nonsignificant change (Table 1). However, in-pool alterations were detectible. Surface area with marine algae present in the water column was reduced to 22% of its former coverage and beds of blue mussels (7% of pool surface area prior to the storm) were extirpated. Concentrations of *Laminaria* spp. were largely absent. Sand filled in 52% of the bottom of the tidepool.

Because of sand deposition, maximum depth was 4.5 cm less than the long-term average. Sand – largely absent from the pool prior to the storm – was 6–10 cm thick where present. Both large and small-size Amphipoda were observed in the tidepool following the storm, along with 14 lumpfish (16–23 mm), 6 Atlantic seasnail (20–49 mm), and 2 grubby (54, 70 mm). Prior to Hurricane Bob, five fishes of three species were collected.

Pool B

The smallest tidepool, formed between two rock walls, did not show a significant change in pool surface area after the passage of Hurricane Gloria (Table 2). The slight reduction was well within measuring error. The proportion of marine algae in the post-storm pool was slightly higher, but statistically insignificant ($P<0.05$).

Unlike the situation in Pool A, Isopoda and other mobile invertebrates were present. Dislodged remnants of crustose coralline algae, previously dense along the eastern rock wall (facing the path of the oncoming hurricane), were strewn along the bottom of the tidepool. No fishes were encountered during the pre-storm or poststorm visits, although several species of fishes had been collected in the tidepool in previous collecting trips.

Pool C

The largest pool was radically altered after the passage of Hurricane Gloria. This tidepool is shallow, formed in a broad recess on a beach strewn with small rocks, and facing the direct path of the hurricane. Without permanent rock boundaries for the pool, physical integrity broke down during the storm. Surface area increased by 28% due to physical displacement of rocks that previously formed the perimeter of the pool (Table 3) and maximum depth was 6 cm less than the average from previous years of sampling. Most of the tidepool was less than 15 cm in depth – the result of sand deposition.

The portion of the tidepool bottom that was covered with sand increased from 16% to 37% following Hurricane Gloria. Beds of eel grass, *Zostera marina*, were unchanged following the hurricane, accounting for 34% of the surface area in each instance. There was obvious evidence of scouring of about 20% of the rocks on the west side of the tidepool (initial impact of storm), with crustose coralline algae stripped from rocks. Isopoda and Mysidacea were abundant and six fishes were collected: two lumpfish (20, 29 mm), three shorthorn sculpin (56, 57, 167 mm), and one rock gunnel, *Pholis gunnellus* (102 mm). During the previous visit to this tidepool, 23 fish were collected (20 lumpfish, 9–15 mm; 1 rock gunnel, 124 mm; 1 grubby, 67 mm; and 1 threespined stickleback, *Gasterosteus aculeatus*, 23 mm).

Pool C also increased in surface area following the passage of Hurricane Bob (Table 3). Surface area increased by 17% and sand deposition on the bottom increased from 66% to 85% of total area following the storm. Beds of eel grass were reduced from 38% of pool area to 15% after the event.

The bottom was littered with green sea urchins, *Strongylocentrotus droebachiensis*, most of them dead. They were apparently washed into the exposed intertidal area and most were broken apart by aquatic birds. However, significant numbers of these largely sub-tidal animals were still alive and displaced eight days after Hurricane Bob. Both small and large-size Amphipoda were abundant, as were 17 lumpfish (9–27 mm), 1 Atlantic seasnail, and 1 rock gunnel. On the previous pre-storm visit, 32 lumpfish were collected (5–17 mm).

Discussion

When a severe storm, such as a hurricane, passes through an area, detrimental effects are often quite variable. The extent of physical or biological damage depends on terrain, animal and plant species present, degree of prior disturbance, direction of storm, and other factors (Walker et al., 1991, 1992). Aquatic systems have been generally quite resilient, except in shallow areas (Fenner, 1991). In sub-tidal waters where artificial reefs have been established or along natural coral reefs or bays, changes in fish and invertebrates are generally short-term and minimal (Breder, 1962; Springer & McErlean, 1962; Fenner, 1991; Bell & Hall, 1994). Rather, damage is highest in the lower portions of river mouths and in coastal tidal flats (Yeo & Risk, 1979; Smock et al., 1994).

The physical parameters of tidepools etched from the rocky intertidal zone in Maine changed little after severe storms. Pool C, with a loosely-defined border, increased in surface area in both instances. However, short-term, in-pool damage was substantial in many cases. Algae was reduced and eel grass beds were significantly uprooted following Hurricane Bob. Sand became a substantial component of bottom topography after both hurricanes, although the excess was eventually removed by wave action and tidal flux in winter months.

From an ecological standpoint, Dethier (1984) concluded that the most severe damage occurs to tidepools in the upper intertidal zone in summer (due to heat stress) and low tidepools in winter (due to wave damage). Such guidelines do not necessarily hold for hurricane events on the coast of Maine. The lower level tidepool (Pool C) was radically altered during these August and September events. In addition to the altered size of the tidepool and increased sand deposition, eel grass beds were significantly depleted during Hurricane Bob. Eel grass is well known for its value as nursery habitat for invertebrates and juvenile fishes (e.g. Moring, 1989; Pohle et al., 1991; Costa et al., 1994) and even dead eel grass has an important ecological role in the intertidal system (Rasmussen, 1973). So, destruction of eel grass can affect survival of and food available to fishes and invertebrates.

The large-scale uprooting of green sea urchins from sub-tidal waters following Hurricane Bob, and the subsequent high mortality during and after the storm suggests possible impacts on the subtidal community as well. Sea urchins normally avoid areas of high turbidity and turbulence and reduce their activity in such stressful environments (Lissner, 1980). Thus, the displacement of these echinoderms to the intertidal zone likely caused the animals to reduce activity further, making them more susceptible to bird predators and altering the immediate intertidal and sub-tidal ecosystems.

Tidepools of the rocky intertidal zone, at the land-sea interface, show remarkable resiliency after hurricanes. The number of fishes declined in Pool A following Hurricane Gloria, but increased after Hurricane Bob. In Pool C, numbers declined following both hurricanes. These storms occurred at the end of summer, when fish numbers are declining in Maine tidepools (Moring, 1990). Yet, by the following summer, numbers of fish in these two tidepools were again comparable to predisturbance levels (Moring, unpubl. data).

Part of the ability of fish populations to compensate for severe physical alterations has to do with the seasonal nature of fishes in tidepools in Maine, their absence in winter, and the role of tidepools as nursery areas for underyearling fishes (Moring, 1990, 1993a, 1993b). The two recent hurricanes in Maine occurred at a time when fish numbers are starting to decline, in concert with declining algal cover. If habitat has been adversely altered, fish may depart for subtidal areas somewhat earlier than normal. By the following spring, when underyearling fishes appear for their first use of tidepool nurseries, excess sand and collected detritus has been largely removed by winter turbulence and the large tidal range off the coast of Maine. As a consequence, although short-term biological and habitat changes are likely following severe storms, tidepool fish communities do appear to recover by the following season.

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