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EFFECTS OF AN OIL SPILL ON EMERGENCE AND MORTALITY IN FIDDLER CRABS *UCA PUGNAX*

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Abstract. Following a spill of 567 000 gallons of No. 2 fuel oil into the Arthur Kill in New York and New Jersey in January 1990 we studied the emergence and mortality of fiddler crabs. We (1) compared seven salt marsh creeks immediately adjacent to the oil spill with 23 creeks at varying distances from the spill; (2) examined the temporal pattern of emergence in one creek; and (3) compared mortality rate of crabs that emerged with those we dug up. Twice as many crabs emerged in the adjacent creeks compared to those that were only 4.5 km away. There were significant differences in the number of crabs that emerged as a function of distance from the spill. Crabs continued to emerge until mid-March. For all the emerged crabs, the percentage of females ranged from 28 to 80, whereas the percentage of females in intact burrows was 64–65%. For all emerged samples, females died earlier than males. In the laboratory, all emerged crabs died within four weeks whereas over 90% of the controls were still alive eight weeks after the initiation of the experiment.

1. Introduction

Marine ecosystems are increasingly exposed to oil contamination as oil exploration and development in the outer continental shelf continues (NAS, 1989), as well as from exposure during the transport and storage of existing resources. Ecosystem or organismic effects from most oil spills go unnoticed and unstudied, although major spills attract media and scientific attention. Two oil spills that generated immediate and long-term studies were those from the *Amoco Cadiz* off the Brittany shoreline (Wolfe, 1978) and from the barge *Florida* at West Falmouth, Massachusetts (Sanders *et al.*, 1980). Both studies reported immediate mortality and the presence of oil or breakdown products in a variety of organisms from plants to zooplankton, a variety of invertebrates, fish, and birds (Chasse, 1978; Jones *et al.*, 1978; Mackie *et al.*, 1978; Sanders *et al.*, 1980).

Immediately following most oil spills large and conspicuous organisms such as birds and marine mammals receive considerable attention, often resulting in rehabilitation attempts. Smaller, less conspicuous organisms are often ignored, or their death is merely noted qualitatively. Even following the West Falmouth spill the presence of dead or moribund organisms was merely reported, but numbers of dead invertebrates such as fiddler crabs (*Uca* spp.) were not examined for many

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months or years (see Krebs and Burns, 1977).

In this paper we report on the emergence and mortality of fiddler crabs *Uca pugnax* following the 2 January 1990 spill of 567 000 gallons of No. 2 fuel oil into the Arthur Kill. The Arthur Kill is a navigable waterway separating Staten Island New York from New Jersey (Burger *et al.*, 1991). The oil escaped from a 6.7 mile pipeline connecting Exxon's Bayway refinery in Linden to its terminal in Bayonne, New Jersey (Engler, 1990). Although some lighter fractions of the oil evaporated or were removed by skimmers, a considerable amount permeated the shoreline and salt marsh creeks (Engler, 1990).

In the weeks immediately following the oil spill we took a census of 24 salt marsh creeks in the impacted areas of the Arthur Kill and Rahway River, and six creeks in the nearby Cheesequake marshes (as a control) for evidence of effects on fiddler crabs. We were particularly interested in whether fiddler crabs would be forced up from their burrows, in mortality rates, and in potential vulnerability as a function of sex or size of the crabs. Further, we continued to survey one creek immediately across from the spill site to determine whether there was a temporal pattern of emergence, and in the laboratory we maintained emerged crabs and crabs we dug from their burrows to determine survival patterns.

2. Study Area and Methods

We conducted a census of 24 creeks in the Arthur Kill and Rahway River, and six creeks at Cheesequake to compare effects on crabs in exposed and control sites. The Arthur Kill separates Staten Island, New York, and New Jersey. We designated creeks immediately across from the spill as 'adjacent', and within 5 km on the Arthur Kill as 'nearby'. Other creeks emptying into the Rahway River, a tributary of the Arthur Kill about 7.5 km from the spill, were called 'Rahway'. The Cheesequake creeks were control sites about 28 km from the spill (Figure 1). Although it appears highly industrialized when viewed from nearby highways, the waterway is surrounded by extensive salt marshes, and three islands in the Kill support extensive heronries and gulleries (Burger *et al.*, in press). The nesting herons, egrets, ibises and gulls feed within the salt marshes and along the Kill itself, and migrants and overwintering birds use the area as well.

Cheesequake is a salt marsh ecosystem, located about 26–29 km from the site of the spill, draining into Raritan Bay. Physiognomically the different salt marsh ecosystems with their associated salt marsh creeks appeared similar. All creeks were off other, larger, tidal creeks, and were narrow (< 5 m) and shallow, decreasing differences in habitat effects on densities of fiddler crabs.

We selected our sample sites as a gradient of oil exposure based on estimates of oil contamination from New York and New Jersey state agencies involved in the clean-up operations.

We sampled each creek in the Arthur Kill area and at Cheesequake from 15 January to early March 1990. Although we sampled over a two month period, we

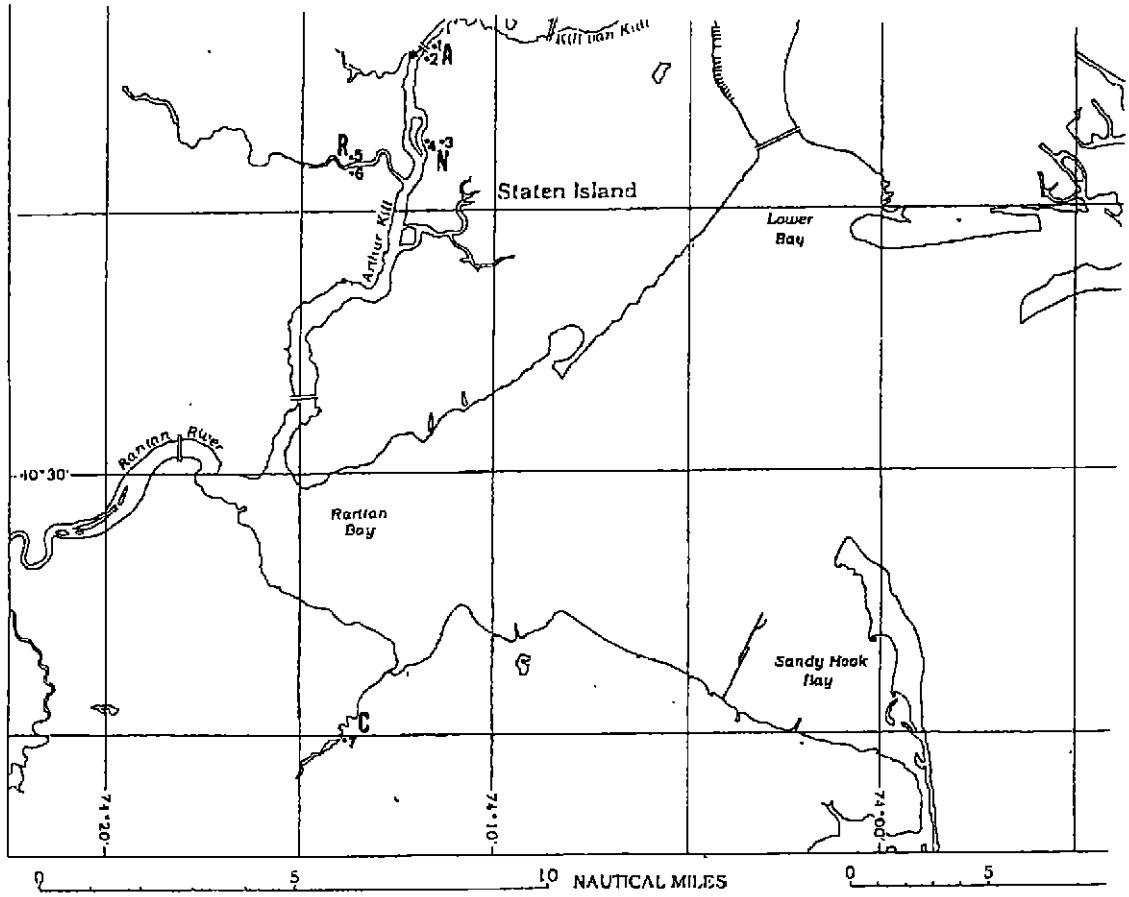

Fig. 1. Sample sites on the Arthur Kill, Rahway, and Cheesequake. The oil spill was at *, A = adjacent creeks, N = nearby (4.5 km), R = Rahway (7.5 km) and C = Cheesequake (28.5 km away). Dots represent survey sites.

distributed our sampling in the four types to minimize seasonal or temperature differences. Thus, some creeks in all four areas were sampled early and late. We followed similar procedures at every creek. We sampled a 10–60 m long sample of each creek (depending on physiognomy), dividing each into one-meter sections. Our sample started at the creek mouth. We then standardized our data by computing the number of crabs per 10 m of creek length. During each sample we collected every crab visible on the surface. We later recorded the condition of all crabs (live, moribund or dead) and identified the sex.

In one creek immediately across from the spill site (J's Creek emptying into Old Place Creek) we sampled every 3–8 days until 3 April 1990 to observe the pattern of emergence. Prior to the first census we removed all crabs, and these may have emerged anytime from 2 January to 14 January. During each subsequent census we collected all crabs so we would determine the emergence pattern.

TABLE I
Comparison of fiddler crab emergence as a function of distance from 2 January 1990 oil spill. Crab emergence was examined once per creek.

Type	Distance from spill (km)	Number of Creeks sampled	Total number crabs emerged	Number crabs per 10 m
Adjacent	0	7	94	4.75
Nearby	4.5	5	49	2.05
Rahway	7.5	12	3	0.06
Cheesequake	28.5	6	7	0.40
Contingency $\chi^2(p)$				246.6(< 0.048)

To separate the effects of early emergence and cold from the presence of oil we also dug up some crabs from their burrows in a creek in the oil spill area. We maintained these crabs, along with the sample of recently-emerged crabs from the Arthur Kill, in the laboratory to assess mortality. We also had access to a laboratory sample of fiddler crabs collected alive on the mud surface at Pyles Creek in September 1989. This site is about 2 km from the site of the subsequent spill. Subsequently we collected a sample in mid-June, and kept these in the laboratory as well. We maintained crabs in open plastic terraria on moist mud from Cheesequake. They were kept at 24° ± 1°C on a natural light-dark cycle.

3. Results

3.1. Presence of Emerged Crabs

We found crabs (both live and dead) in all four sample areas (Table I). However, the number of crabs that emerged varied significantly as a function of distance from the oil spill (Table I). Over 90% of the crabs were *Uca pugnax* (the remainder being *U. minax*), only data for *pugnax* are considered.

3.2. Temporal Pattern of Emergence

We surveyed J's Creek every 3–8 days from mid-January until early April, after which no more crabs emerged until early May, when the fiddler crabs began to emerge naturally due to warm weather. From mid-January until mid-February crabs emerged at a steady state of 50–73 crabs every 3–8 days (Table II). During most of our visits over 60% of these crabs were moribund or dead, and the percent that was alive was greatest when we had removed all crabs only three or four days before (Table II).

Overall the sample contained 28–68% females (Table II). Females seemed to have lower survival after emergence in that fewer females were alive at each collection compared to males (Table II).

TABLE II

Uca pugnax collected in J's Creek on successive days. All crabs present on a visit were collected.

Date		Number Collected	Percent dead or Moribund	Percent Females	Percent live that are females
January	20	50	70	56	53
	23	61	43	61	57
	27	50	62	68	68
February	6	62	65	60	43
	12	69	80	57	30
	19	73	79	59	20
	24	25	64	28	11
March	1	12	58	42	20
	8	8	62	50	0
	14	2	50	50	0
	27	0	–	–	–
April	3	0	–	–	–

3.3. Survival in the Laboratory

During each of our collections at J's Creek, from 20–57% of the crabs were alive and active. We defined active as walking spontaneously and readily able to right themselves when placed on their backs. We compared survival of these emerged crabs with controls in the laboratory (Table III).

Half of the emerged crabs ($N = 61$) taken to the laboratory died within the first week, whereas only one of the 75 crabs that were dug up died within the first week. At the end of five weeks no emerged crabs were alive, and over 95% of the crabs that were dug from their burrows were still alive and active regardless of when they were dug up (Table III). We terminated the experiment at the end of eight weeks (when over 90% of the controls were still alive), and returned the crabs to the field.

4. Discussion

4.1. Emergence of Crabs

During the winter months fiddler crabs in temperate regions normally reside in underground burrows that are steeply inclined or vertical (Powers, 1976). *Uca pugnax* burrows normally range from 10 to more than 50 cm deep (Krebs and Burns, 1977), and the burrows are extremely important because crabs position themselves within them to maintain a favorable temperature regime (Powers, 1976). In the winter months crabs put a mud plug near the burrow entrance (R. Loveland,

TABLE III

Survival of Fiddler Crabs that emerged in oil-contaminated creeks compared to controls dug up from their underground burrows. All crabs were maintained in the laboratory at 24°C in plastic cages.

	Crabs that emerged in oil			Control Crabs			
	27 January	12 and 19 February 1990	1 and 8 March 1990	Mid September[a] 1989	13 February 1990	14 March 1990	15 June 1990
Initial Number	31	30	20	17	22	23	30
Percent Females	68	25	40	60	64	65	63
Survival (%) for							
One week	48	50	60	100	100	100	97
Two weeks	29	33	45	100	95	100	97
Three weeks	6	20	20	100	95	96	97
Four weeks	0	7	5	100	95	96	97
Five weeks	0	0	5	94	95	96	97
Eight weeks	0	0	0	94	91	96	90

[a] Pre-spill, maintained in laboratory at 5–6°C until late March.

personal communication), which presumably reduces the entrance of cold air.

The lower limit of *Uca pugnax* activity range is about 13°C, and they normally emerge from their underground burrows in May (Krebs and Burns, 1977). In some species of *Uca*, temperatures below 20°C inhibit surface activity (Powers and Cole, 1976). Although northern species of *Uca* can survive exposure to low temperatures of 7°C, they remain inactive (Vernberg and Tashian, 1959).

Following the 2 January 1990 oil spill fiddler crabs in the Arthur Kill emerged from their underground burrows, and remained fairly inactive on the mud and in the water. Presumably the oil seeped down through the mud into their burrows, coating them, and forcing them to the surface. The emerged crabs we collected were always coated with oil, and washing removed the oil. Eventually they simply died, presumably from a combination of oiling and cold temperatures.

4.2. Temporal Pattern of Emergence

On the creek that we censused regularly from January to early April we found that crabs continued to emerge at the same relative level until the end of February, when numbers decreased. This suggests that the factors causing emergence acted differentially on different crabs. Since we surveyed the same section of the creek on successive days, these differences were not due to creek structure or salinity differences.

Differences in burrow structure or depth, or soil properties could account for

variable exposure and continued emergence. In a study of *Uca pugnax* in Massachusetts, Krebs and Burns (1977) found some burrows were nearly vertical while others were horizontal. Presumably oil would penetrate a vertical burrow more quickly, forcing crabs to the surface more rapidly than burrows that have horizontal sections. Further, the thickness of the mud plug might also retard oil penetration.

4.3. Rates of Emergence

Rates of emergence differed both within the Arthur Kill and between the Arthur Kill and Cheesequake. On the March census at Cheesequake there were only two fiddler crabs (live or moribund) on any of the sampled creeks. On the Arthur Kill the number of crabs that emerged varied somewhat by creek (refer to Table II). There are several possible explanations: (1) oil exposure varied as a function of distance from the spill or there was subsequent differential movement of the oil; (2) initial crab density differed among creeks; and (3) initial crab burrow locations (depth or structure) varied among creeks.

Initial oil exposure clearly varied among creeks because strong winds blew the oil to the Staten Island side of the Arthur Kill. Differences in oil exposure were visible as differences in the amount of *Spartina* oiled along the creek beds. Further, not all creeks have similar flushing rates, accounting for differences in oil removal once it entered a creek.

4.4. Sexual Differences

Normal *Uca pugnax* populations are 40% females (Wolfe *et al.*, 1975). In their West Falmouth study Krebs and Burns (1977) reported 40.8 ± 2.4% females for *U. pugnax* from their control site, but only 17.5 ± 5.4% in oiled stations. In the Arthur Kill we found that 58% of the winter emergent, oiled crabs, and 64% of the control crabs dug up from their underground burrows were females.

In our temporal series of emerged crabs, the number of females ranged from 28–68%. The number of emerged females rose slightly, and then decreased in late February and March. These differences may have been due to burrow differences or sexual differences in metabolism (see Vernberg and Vernberg, 1972).

4.5. Survival of Emerged and Control Crabs

When we collected crabs that had emerged following the oil spill and brought them to the laboratory, many were still active and appeared normal. However, these crabs were behaviorally impaired (Burger *et al.*, 1991) and did not survive beyond five weeks. We attribute differences in survival among the oiled crabs to exposure differences. When we collected crabs on 27 January, and on 12 and 19 February the crabs could have emerged immediately after our departure from the previous survey, or at any time up until our present survey. Thus crabs might have been exposed for up to six days. Presumably the dead crabs were exposed for longer than the apparently healthy, active crabs. Indeed as we walked the survey area we

occasionally saw a crab emerge.

However, even when moved to a clean environment in the laboratory, the emerged crabs continued to die whereas the control crabs did not. Since the control crabs did not die we assume that the laboratory conditions were sufficient for maintenance.

One other possibility is that the emerged crabs were exposed to cold on the surface and that the differences in mortality in the lab reflect cold stress rather than exposure to oil. We feel this is not the case for several reasons: (1) January was very warm and air temperatures ranged as high as the low 20°C range, thus the emerged crabs were at warmer temperatures than those residing in their burrows (at 8°C); (2) crabs that were dug up were kept at ambient temperatures in the marsh for several hours before being brought back to the laboratory. Thus, the crabs from 12 (emerged) and 13 (dug up) February were maintained for several hours in the field at the same temperature before bringing them to the lab.

Overall our observations suggest that fiddler crabs were forced from their winter burrows by an oil spill. They continued to emerge for over two months after the spill. Once emerged, the crabs became moribund and died. Those that survived and were removed to a laboratory continued to die whereas crabs that were dug from their burrows left on the surface for equivalent periods of time and maintained in the same laboratory under the same conditions did not die. Our results suggest that the effects of a winter oil spill can be severe, forcing fiddler crabs from their burrows, and resulting in their death.

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