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CAROLINIAN RECORDS FOR AMERICAN LOBSTER, *HOMARUS AMERICANUS*, AND TROPICAL SWIMMING CRAB, *CALLINECTES BOCOURTI*. POSTULATED MEANS OF DISPERSAL

Recent reports of distributional extension for decapod crustaceans occurring along the east coast of the United States include two poorly substantiated records of American lobster, *Homarus americanus* H. Milne Edwards, and none of the tropical swimming crab, *Callinectes bocourti* A. Milne Edwards, from the Carolinas south of Cape Hatteras, N.C. (Williams 1965, 1974 [Carolinas]; Cerame-Vivas and Gray 1966 [Cape Hatteras]; Williams et al. 1968 [North Carolina]; Musick and McEachren 1972 [North Carolina-Virginia]; Milstein et al. 1977 [New Jersey]; Bowen et al. 1979 [Middle Atlantic area]; Herbst, Weston, and Lorman 1979 [Cape Hatteras]; Herbst, Williams, and Boothe 1979 [Capes Hatteras and Lookout]; Wenner and Boesch 1979 [Norfolk Canyon area]; Perschbacher and Schwartz 1979 [North Carolina]). Occurrences of both species in the Carolinas south of Cape Hatteras are documented here along with discussion of their postulated means of dispersal.

Specimens are deposited in the U.S. National Museum of Natural History (USNM), or are living in aquaria at the North Carolina Marine Resources Center, Bogue Banks (NCMRC), and the Hampton Mariners Museum, Beaufort (HMM).

Occurrence of Species

Homarus americanus.—Distribution of the American lobster has been given as, "East coast of America from the Strait of Belle Isle, Newfoundland (Canada) to Cape Hatteras, North Carolina (U.S.A.)," at depths of 0-480 m, usually 4-50 m (Holthuis 1974). Reported occurrences of this species south of Cape Hatteras are: one caught in a

crab pot near Cedar Island, Carteret County, N.C., in December 1958 (Williams 1965), and one doubtful occurrence near Beaufort, N.C. (Hay and Shore 1918). New substantiated records are given in Table 1.

Callinectes bocourti.—The distribution of *C. bocourti* has been given as, "Jamaica and British Honduras to Estado de Santa Catarina, Brazil," with "extraterritorial occurrences in southern Florida and Mississippi..." (Williams 1974). Gore and Grizzle (1974) confirmed Florida occurrences with a note on a mature male from the Indian River, Vero Beach, Fla., slightly larger than our specimens (Table 1). At the time our female was caught, it had a dorsal coloration much as that pictured for the female in color photo 5 by Taissoun (1972), i.e., carapace very dark olive green, but chelipeds moderate "brick" red, much as the male described by Gore and Grizzle (1974), and underparts white. By December, the dorsal greenish coloration of the carapace had faded somewhat, yielding an underlying reddish tone somewhat resembling the color of the male in color photo 5 by Taissoun (1972).

Discussion

What are the explanations for these marginal occurrences? Available evidence comes from known life histories (rates of development and growth, and movements deduced from seasonal and areal sampling), current regimes of waters in which the animals may have lived, and indication of migrations from tagged individuals that have been recaptured.

Lobsters.—There are no known breeding populations of American lobsters south of Cape Hatteras which is generally regarded as the southernmost extent of the cool temperate Virginian Province (Wells 1961; Cerame-Vivas and Gray 1966). Scott (1973), in a general review of lobster life history, pointed out that: 2 yr elapse between mating and hatching of eggs; hatched larvae drift from 2 wk to 2 mo before becoming permanent bottom dwellers; lobsters can be reared experimentally in waters of 22.2° C (72° F) to 0.37 kg (1 lb) weight in 2 yr, but require 5½ yr to reach this size in waters around Martha's Vineyard, Mass., and 8 yr to reach it in Canada.

Movements of tagged lobsters in the region of southern New England analyzed by Uzmann et al. (1977) showed that although courses from point of release to point of recapture cannot be interpreted as straight lines, "...maximum movement of any recapture was 186 nautical miles (345 km) in 71 days (2.6 miles/day)," and other tracks in excess of 100 mi (185 km) in from 29 to 86 days were recorded. Shorter "...apparently directed tracks of 50-87 miles (93-161 km)..." were traversed "...within 22-41 days," the calculated ground speeds of all these ranging from 1 to 5.5 mi (1.8-10.2 km)/day, indicating "...that directional movements in excess of 1 mile (1.8 km) per day are not uncommon...." Moreover, these authors showed that offshore lobsters tend to aggregate along the outer edge and slope of the continental shelf during January-April, but become widely dispersed by migration or random movement in the shoaler, warmer water off southern New England during May through December.

The approximate distance by water from Cape

TABLE 1.—Records of *Homarus americanus* and *Callinectes bocourti* from the Carolinas south of Cape Hatteras. Measurements (millimeters): CL = carapace length in midline, including rostrum of *Homarus*; TL = total length in midline; CW = carapace width including lateral spines, *Callinectes*.

Species	Sex	Measurements		Collection Data	Depository
				North Carolina	
H. americanus	♂	120 CL	257 TL	Jarratt Bay, Core Sound, 25 Oct. 1978, crab pot, R. R. Seely	
	♂	100 CL	230 TL	Bogue Sound off Salterpath, 12 Nov. 1978, crab pot, R. O'Neal	NCMRC living
	♀[1]	95 CL		Nelson Bay, Core Sound, 21 Nov. 1978, crab pot, R. R. Seely	USNM 172262
	♀[2]	95 CL		Near Davis, Core Sound, 29 Mar. 1979, crab pot, P. Apperson	USNM 173231
	♀[3]	110 CL	247 TL	Off Atlantic, Core Sound, 13 Nov. 1979, crab pot, L. Hill, Jr.	NCMRC living
	♀[4]	98 CL	222 TL	Drum Inlet, Core Banks, 28 Nov. 1979, D. Cavett	HMM living
	♂[5]		254 TL	0.8 mi off Rich Inlet, 15 May 1978, trawl, L. Holden on MV *Capt. Jason*	USNM photos
C. bocourti	♀	63 CL	130 CW	Sound behind Carolina Beach, mid-Oct. 1977, crab pot, by fisherman	USNM 170863
				South Carolina	
	♂	67 CL	128 CW	Wando R., Charleston, 4 Oct. 1977, crab pot, G. Steele, P. Eldridge, V. A. Burrell, Jr.	USNM

[1]Rostrum tip broken, length approximate; abdomen damaged.
[2]Maintained in aquarium in NCMRC until 4-5 October 1979 when killed at night by tank mate; abdomen damaged.
[3]Carapace encrusted with two species of barnacles, singly and in patches. Largest of these removed and measured at greatest diameter 24 December 1979: *Chelonibia patula* (Ranzani), 7.6 × 9.0; *Balanus venustus* Darwin, 6.4 × 6.8.
[4]Few small *B. venustus* on carapace.
[5]Measurement given to us.

Hatteras to Rich Inlet, around Cape Lookout, is 130 nmi (240 km). A narrow, southerly longshore current of Virginian water continues past Cape Hatteras (Bumpus 1973), reaching well beyond Cape Lookout in some winters (Wells 1961), which conceivably could aid southward movement of lobsters. The current contributes to what Watling (1979) and others have considered as part of a shallow nearshore and estuarine "transhatteran" zone. While the lobster larval phase might be dispersed southward from breeding populations living in cooler water by this means, survivors of such movement must be rare and would have to exist for at least two seasons in warm temperate Carolinian waters that are heavily trawled for penaeid shrimps in order to attain the sizes recorded in Table 1 (from growth rates calculated by Hughes and Mathiessen 1962, and accelerated growth rates indicated by Scott 1973). The dispersed phase of older lobsters (Uzmann et al. 1977), however, might utilize this nearshore southerly drift, and migrate southward in one season when they had reached essentially the size at which they were caught.

Crabs.—The northernmost occurrences of tropical crabs such as *C. bocourti*, *C. danae* Smith, and *C. marginatus* A. Milne Edwards in the western Atlantic have been attributed to drift of larvae entrained in currents associated with the Gulf Stream, or to drift of postlarval crabs (juveniles or subadults) with debris, or transport on boats (Williams 1974). Zoeae spawned in southern Florida, or perhaps Cuban waters, conceivably could be swept northward in favorable warm seasons to be introduced to shores of the Carolinian Province (Williams 1965). Later growth stages of crabs might be transported with the aid of swimming or in association with flotsam. Evidence of drift from the tropics deposited along the Carolina shores is provided by strandings of 22 species of sea-beans (*Mucuna* spp.), red mangrove (*Rhizophora mangle* Linnaeus) seedlings, and mango fruits (*Mangifera indica* Linnaeus) (Gunn and Dennis 1976), palm trunks and coconuts, bamboo, Portuguese man-of-war (*Physalia*), gulfweed (*Sargassum*), etc. observed along Bogue Banks, Core Banks, and Cape Lookout, especially following southerly storms.

Perschbacher and Schwartz (1979) reported *C. danae*, *C. marginatus*, and *C. ornatus* in the Intracoastal Waterway south of Carolina Beach Inlet, New Hanover County, in mid-September 1977, and in the nearby Cape Fear River in mid-October 1977; *C. ornatus* was already known from the Carolinas and *C. marginatus* recorded once near Beaufort (Williams 1974). Milstein et al. (1977) reported another tropical species, *Cronius ruber* Lamarck, collected off Little Egg Inlet, N.J., on 27 September 1974 (size unrecorded), from an engine block.

Callinectes specimens of the sizes reported here and by Perschbacher and Schwartz (1979) are mature (Williams 1974). The growth rates of *C. bocourti*, *C. marginatus*, *C. danae*, and *C. ornatus* are unknown, but if they are similar to that of *C. sapidus* these crabs were at the end of their second summer of life when caught. Their presence in the Carolinas at this size in late summer-early fall would have to result from: 1) transport of zoeae or megalopae into Carolinian waters during the previous summer or fall, and overwintering as juveniles to mature during the second summer of residence; 2) transport to Carolinian waters as juveniles in spring to mature during their second summer; or 3) transport to the Carolinas as subadults or adults sometime during the summer preceding capture. Presence of four tropical species together, two in considerable numbers, far beyond their normal range (Perschbacher and Schwartz 1979), suggests something other than casual transport, perhaps an unusually mild winter preceding the season of capture, a major eddy(ies) in the Gulf Stream, or major southern storm(s).

Callinectes sapidus requires temperatures >20° C for hatching, development, and survival of larvae (Costlow and Bookhout 1959; Costlow 1965, 1967). During larval development, the zoeal stages of *C. sapidus* are found at sea seasonally (see Williams 1974 for review), but megalopae return to estuaries for development into adults. Estuarine water temperatures in the Beaufort area commonly fall below 10° C in winter (Williams et al. 1967); in South Carolina such temperatures are normally higher, 9.4° C and above in 1973-74 (Mathews and Shealy 1978), for example. The winter of 1976-77 was abnormally cold in the eastern United States, the subnormal trend continuing into summer at sea (Ingham 1979). January water temperatures as low as 2° C were recorded in the bight of Cape Lookout (R. S. Fox[1]).

[1]R. S. Fox, Department of Biology, Lander College, Greenwood, SC 29646, pers. commun. May 1979.

Presumably the above tropical species have development similar to that of *C. sapidus*. If they could survive winter temperatures such as those given above, their normal ranges would extend to Cape Hatteras; therefore, overwintering as juveniles in Carolinian waters during 1967-77 seems unlikely.

Spin-off eddies along the western boundary of the Gulf Stream are regular features (Lee 1975). These cyclonic current reversals are not wind or

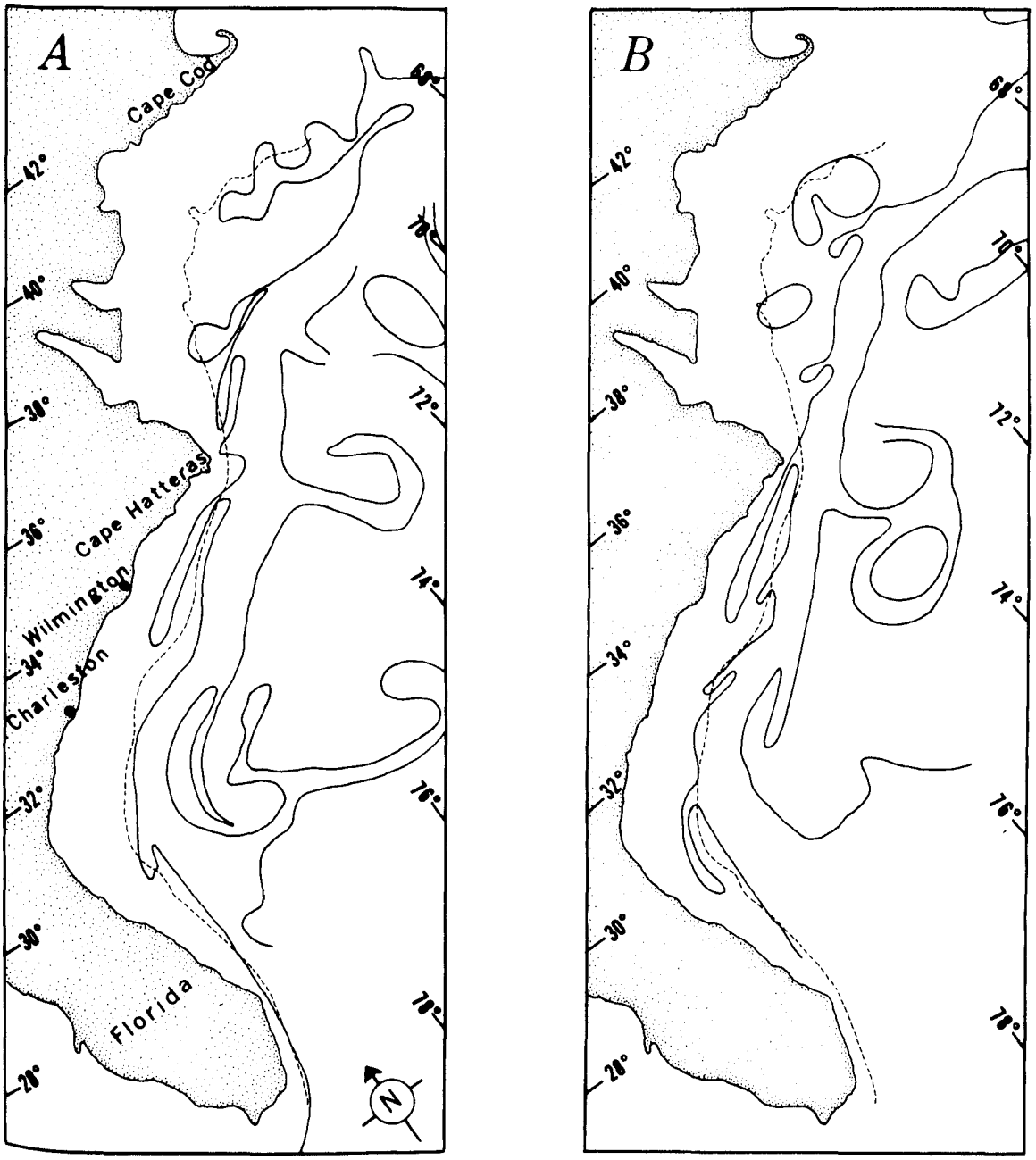

FIGURE 1.—Gulf Stream off eastern United States between Florida and Cape Cod; isopleths represent maximum thermal gradients at edges of spin-off eddies near shore and Gulf Stream meanders seaward as viewed by National Environmental Service Satellite and analyzed by Miami Satellite Field Services Station for weekly loop periods. Example plots: *A*, 26 April-2 May 1977; *B*, 10-16 May 1977.

tide induced. Figure 1 shows reproductions of Gulf Stream surface features taken from National Environmental Satellite Service charts analyzed by the Miami Satellite Services Station for two weekly periods in April and May 1977. The warm season is judged to be roughly the time during which surviving juvenile or adult crabs might be carried into the Carolinian Province by such eddies, hence accounting for the tropical *Callinectes* spp. collected in 1977. During late April to mid-June of this period, prominent spin-off eddies were developed along the coast (least evident at the surface when summer gradients are minimal). There is nothing to suggest that spin-offs during summer 1977 were unusual, but they appear to have been more prominent than such features indicated by surface isotherms in 1976 (Deaver 1979). These currents augment inshore and southerly drift indicated by drift-bottle returns in shelf waters along the Carolinas in May-June (indeterminate in July), August and September (Bumpus 1973; Barans and Roumillat 1978), and seabed drifter returns during the same period (Bumpus 1973). A mechanism to aid shoreward movement of tropical crabs seems to be present.

There is no record of unusual southerly storms during spring-summer of 1977 (Anonymous 1977a, b).

Are juvenile or adult *Callinectes* spp. ever found at sea? Admittedly, there is little evidence at hand. Most records of distribution for members of the genus are nearshore or estuarine, but Franks et al. (1972) recorded both *C. sapidus* and *C. similis* in trawl samples taken at depths of 9-90 m off Mississippi and on 29 May 1968 observed hundreds of nocturnally swimming small *C. similis* (40 mm carapace width) at the surface in 9 m water in an apparent inshore migration. *Callinectes sapidus* has been observed to move 90 mi (144.8 km) in 10 d in Chesapeake Bay (R. E. Miller[2]). Gunter (1950) reported mature female *C. danae* (= *similis*) at the surface several miles from the Texas shore in the Gulf of Mexico. All species of *Callinectes* have broad salinity tolerances. Although Norse (1978) regarded *C. bocourti* as occurring mainly in low salinities, he ordered *C. danae*, *C. marginatus*, and *C. ornatus* at the high end of the salinity tolerance scale for the genus, indicating ability to exist in full seawater.

Data on geographic ranges of species result from the amount of field work expended in finding them, coupled with study and identification. The marine species list for the Carolinas has expanded greatly in this century with the growth of laboratories in the area. So-called rare occurrences may result from simple lack of collecting, but in this case we feel that rarity is genuine because of the intense sampling effort expended in the area during the time considered. The South Carolina Marine Resources Center maintained an intensive estuarine benthic survey along the state's coast for 2 yr, 1973-74 (Bishop and Shealy 1977; Mathews and Shealy 1978); F. J. Schwartz[3] maintained an intensive gill net and trawl survey of the lower Cape Fear River, N.C., and adjacent waters in all seasons of the year from 1973 to 1978, consisting of 10,646 units of effort (6,828 20-min river trawls, 3,818 24-h river gill net sets, 1,531 30-min ocean trawls). The above crab records, with one exception, come from the latter effort or from personnel associated with the former, and are the only such occurrences recorded during this period.

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[2]R. E. Miller, Horn Point Environmental Laboratories, University of Maryland, Cambridge, MD 21613, pers. commun. October 1979.

[3]F. J. Schwartz, University of North Carolina Institute of Marine Sciences, Morehead City, NC 28557, pers. commun. August 1979.

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MORTALITIES OF ATLANTIC HERRING, *CLUPEA H. HARENGUS*, SMOOTH FLOUNDER, *LIOPSETTA PUTNAMI*, AND RAINBOW SMELT, *OSMERUS MORDAX*, LARVAE EXPOSED TO ACUTE THERMAL SHOCK

Entrainment of larval fishes through condenser cooling systems of electric generating stations often results in acute physical, chemical, and thermal stresses. These stresses are often lethal and the resulting mortalities could have adverse effects on populations proximal to the cooling water intake site. This is particularly true for fishes which have planktonic larvae (Schubel et al. 1978).

The rapid increase in temperature associated with passage through condenser cooling systems is seldom if ever experienced by organisms in the natural environment. Little is known of the ability of the larvae of most species of fish to withstand this kind of thermal stress. In assessing thermal stresses it is important not only to investigate the effect of different increases in temperature from some base temperature (ΔT), but also to investigate the effect of the duration of the exposure. The simplest simulation experiment, then, is one in which larvae are exposed to a rapid increase in temperature, are held at the elevated temperature for a period of time, and are then returned rapidly to the original base temperature.

Our experiments were designed to evaluate the thermal tolerances of three species of larval fish occurring in the Gulf of Maine and its estuaries: Atlantic herring, *Clupea h. harengus*, smooth flounder, *Liopsetta putnami*, and rainbow smelt, *Osmerus mordax*. These fish, although differing somewhat in their life histories, are all common in inshore areas during some part of their larval life, and are therefore subject to power plant entrainment. This paper presents the results of thermal tolerance experiments which encompassed the range of temperatures planktonic organisms encounter in condenser cooling systems.

Methods

All larvae used in the experiments were reared in the laboratory. Atlantic herring eggs and milt were stripped from ripe adults captured off Gloucester, Mass. The eggs were fertilized and held in 2 l shallow glass bowls of filtered seawater (31.8‰) at approximately the ambient temperature where the adults were collected (8°±1° C). Most of the larvae hatched after 13 d. Ripe adult smooth flounder were collected from Montsweag Bay, part of the Sheepscot River estuary, Maine. Eggs and milt were stripped from the adults, the eggs fertilized, and also kept in 2 l shallow glass bowls of filtered seawater (25.5‰) at the ambient temperature (4°±1° C). The larvae began to hatch after 21 d but the majority hatched after 27 and 28 d. Fertilized rainbow smelt eggs were collected directly from a spawning site in Wiley Brook, a tributary of the Damariscotta River estuary, Maine. The eggs were kept in 40 l aquaria with filtered brook water at the ambient temperature (13°±1° C). The brook water was treated with streptomycin and penicillin according to methods described in Shelbourne (1964) and malachite green hydrochloride was added to control fungal growth. Some of the rainbow smelt larvae began to