LAURS, R. M., AND R. J. LYNN.

1977. Seasonal migration of North Pacific albacore, *Thunnus alalunga*, into North American coastal waters: Distribution, relative abundance, and association with Transition Zone waters. Fish. Bull., U.S. 75:795-822.

LOWMAN, F. G., T. R. RICE, AND F. A. RICHARDS.

1971. Accumulation and redistribution of radionuclides by marine organisms. *In* Radioactivity in the marine environment, p. 161–199. Nat. Resour. Counc., Natl. Acad. Sci., Wash., D.C.

LOWMAN, F. G., AND R. Y. TING.

1973. The state of cobalt in seawater and its uptake by marine organisms and sediment. *In* Radioactive contamination of the marine environment, p. 369–384. Int. At. Energy Agency, Vienna.

OSTERBERG, C., N. CUTSHALL, AND J. CRONIN.

1965. Chromium-51 as a radioactive tracer of Columbia River water at sea. Science (Wash., D.C.) 150:1585-1587.

OTSU, T., AND R. N. UCHIDA.

1963. Model of migration of albacore in the North Pacific Ocean. U.S. Fish Wildl. Serv., Fish. Bull. 63:33-44.

PEARCY, W. G.

1973. Albacore oceanography off Oregon—1970. Fish. Bull., U.S. 71:489-504.

PEARCY, W. G., AND C. L. OSTERBERG.

1968. Zinc-65 and maganese-54 in albacore *Thunnus alalunga* from the west coast of North America. Limnol. Oceanogr. 13:490-498.

PILLAI, K. C., R. C. SMITH, AND T. R. FOLSOM.

1964. Plutonium in the marine environment. Nature (Lond.) 203:568-571.

POWELL, D. E., D. L. ALVERSON, AND R. LIVINGSTONE, Jr.

1952. North Pacific albacore tuna exploration—1950. U.S. Fish. Wildl. Serv., Fish. Leafl. 402, 56 p.

REICHLE, D. E., P. B. DUNAWAY, AND D. J. NELSON.

1970. Turnover and concentration of radionuclides in food chains. Nuc. Saf. 11:43-55.

SVERDRUP, H. U., M. W. JOHNSON, AND R. H. FLEMING.

1942. The oceans, their physics, chemistry, and general biology. Prentice-Hall, Inc., N.Y., 1087 p.

U.S. ENVIRONMENTAL PROTECTION AGENCY (previously Public Health Service).

1960–72. Radiation data and reports, 1960 through 1972. (Mon. Rep.) U.S. Gov. Print. Off., Wash., D.C. 13 vol.

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LENGTH–WIDTH–WEIGHT RELATIONSHIPS FOR MATURE MALE SNOW CRAB, *CHIONOCOETES BAIRDI*

Snow crabs have been exploited commercially in Alaska since 1961 (Alaska Department of Fish and Game 1975). *Chionocoetes bairdi* is the predominant species with *C. opilio* composing up to 25% of the catch from the Bering Sea. Landings were small and intermittent in the early 1960's but increased to about 3.2 million lb in 1968. Landings expanded dramatically thereafter and exceeded 60 million lb in 1974, with an ex-vessel value of more than $12 million.

Carapace width measurements have been collected from the commercial snow crab catch by biologists since the inception of the fishery; individual weights, however, are not routinely collected because the task is rather time-consuming. The relationships between carapace width, length, and body weight are of interest to biologists and processors. The relationship between carapace length and width is of interest because the carapace shape is one of the diagnostic characteristics to distinguish between *C. bairdi* and *C. opilio* and hybrids of the two species (Karinen and Hoopes 1971). The relationships between carapace width and weight and carapace length and weight have many uses. They are, for example, indicators of condition, used to calculate biomass, and used to estimate recovery of edible meat from crabs of various sizes.

Materials and Methods

Carapace length and width and body weight measurements were taken from 240 mature male *C. bairdi* from commercial catches made south of the Alaska Peninsula in the vicinity of the Shumagin Islands in May 1975. Length and width measurements were taken to the nearest millimeter with vernier calipers and weights were recorded to the nearest gram. Length was measured from the posterior medial edge of the carapace to the anterior medial point of the right orbit. The rostrum was not included in the length measurement because it often erodes when crabs are carried in the live tank of fishing vessels. Width was measured at the widest part of the carapace and included the lateral branchial spine. Width ranged from 128 to 185 mm, weights from 635 to 2,230 g, and lengths from 92 to 143 mm.

The basic linear regression formula $W = a + bL$ was used to express the relationship between width (W) and length (L). Weight (Wt) was related to width and length by the power functions, $\log_{10} Wt = \log_{10} a + b \log_{10} W$ and $\log_{10} Wt = \log_{10} a + b \log_{10} L$. The constants a and b were determined empirically.

Results

The length–width, length–weight, and width–weight relationships are summarized in Table 1. All relationships were characterized by very high correlation coefficients. No relationships between length, width, and weight have previously been reported for *C. bairdi*.

TABLE 1.—Length–width, length–weight, and width–weight relationships for mature male *Chionocoetes bairdi*. [Sample size was 240 animals for each relationship.]

Relationship	Coefficient	Formula
Length–width	0.96	$W = -3.584 + 1.268L$
Length–weight	0.99	$\log_{10} Wt = -3.076 + 2.956 \log_{10} L$
Width–weight	0.99	$\log_{10} Wt = -3.363 + 2.936 \log_{10} W$

Literature Cited

ALASKA DEPARTMENT OF FISH AND GAME.
1975. Alaska 1974 catch and production, commercial fisheries statistics. Alaska Dep. Fish Game Stat. Leafl. 27, 49 p.

KARINEN, J. F., AND D. T. HOOPES.
1971. Occurrence of Tanner crabs (*Chionocoetes* sp.) in the Bering Sea with characteristics intermediate between *C. bairdi* and *C. opilio*. (Abstr.) Proc. Natl. Shellf. Assoc. 61:8–9.

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TEMPORAL ASPECTS OF CALLING BEHAVIOR IN THE OYSTER TOADFISH, *OPSANUS TAU*

The oyster toadfish, *Opsanus tau* (Linnaeus), produces two calls: an agonistic grunt and a boatwhistle associated with courtship (Fish 1954; Tavolga 1958, 1960; Gray and Winn 1961). The boatwhistle is produced only by males on nests (Gray and Winn 1961) and is endogenously driven as well as influenced by calling of surrounding males (Winn 1964, 1967, 1972; Fish 1972). A toadfish, not hearing other males, may still boatwhistle for long periods and attract a female. Although toadfish may be influenced to call by the calling of adjacent males, one would assume the circadian patterning of the boatwhistle to be influenced by photoperiod and the fish's behavioral strategy relative to it. Additionally, the rate of calling may be a key to a male's internal state. Calling rate has been manipulated experimentally (Winn 1967, 1972; Fish 1972; Fish and Offutt 1972), but no one has studied the calling rate of undisturbed individual fish. This note is a preliminary attempt to look at these twin problems (when and how fast toadfish call) by recording the boatwhistles of individual males on their nests.

Materials and Methods

Terra cotta drainage tiles were set out individually adjacent to the pilings of a dock at Solomons, Md. Male toadfish which settled into three of the tiles started calling, and the calls were monitored between 9 and 15 June 1969. Because of changing tapes and mechanical problems, the record was not continuous. The recording system consisted of individual Clevite[1] oyster (CH 15-J) hydrophones with their own General Electric Phono-Mic preamplifiers (UPX-003C) and a Precision Instrument Model 207 multichannel tape recorder. The gain was turned down so that only boatwhistles from the fish in the tile adjacent to the hydrophone would present a loud signal. The tapes were transduced onto strip chart paper (Bruel and Kjaer level recorder type 2305), and segments equivalent to 6 min of real time were continuously marked on the chart paper. The number of boatwhistles in each segment was counted.

Results

The activity patterns for the three fish appear aperiodic (Figure 1; Table 1). All of the animals called both day and night (11 calling periods day, 9 night), and the total number of boatwhistles produced for day and night was similar (7,905 day, 6,202 night). Considering the data on a calls-per-hour basis, since daylight hours exceed nighttime in June, does not appreciably alter the results. The fish averaged 41.3 boatwhistles/h during the day and 46.1/h at night from recordings covering 191.5 h of daylight and 134.5 h of darkness. Not only were crepuscular peaks absent, but dawn and dusk appeared irrelevant as cues for calling behavior. There are similarities between certain periods in the data, such as the nights of 14 and 15 June for channel 2, but these similarities are a

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

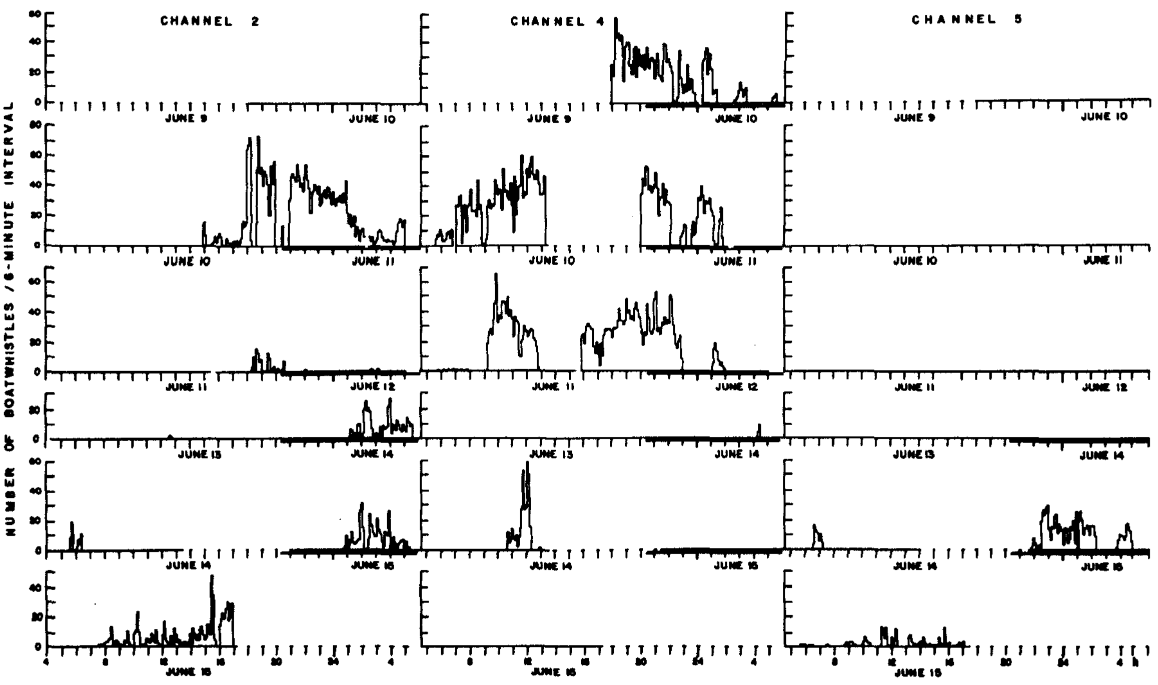

FIGURE 1.—Temporal record of boatwhistle production for each of three toadfish. A missing baseline indicates gaps in the record, and the horizontal line below the baseline indicates the period of darkness.

TABLE 1.—Number of boatwhistles produced during 24-h periods by three toadfish.
[L is light, D is dark, and dash indicates no data.]

	Channel 2		Channel 4		Channel 5	
Date	L	D	L	D	L	D
June 9-10	0	0	849	951	0	0
10-11	890	1,838	2,315	1,103	0	0
11-12	87	11	2,435	848	0	0
13-14	4	364	0	14	0	0
14-15	51	354	355	0	63	719
15	650	—	0	—	206	—
Total	1,682	2,567	5,954	2,916	269	719
Periods called	5	4	4	4	2	1
Total D/total L	1.53		0.49		2.67	

minor feature of the record. Each of the fish produced different numbers of boatwhistles and exhibited separate patterns of calling (Figures 1, 2; Table 1) that were not obviously correlated with each other. One fish (channel 4) boatwhistled twice as much during the day as at night, while the other two (channel 2 and 5, respectively) called 1.5 and 2.7 times more at night than during the day. These ratios from Table 1 change to 2.24, 0.66, and 3.92, respectively when considered on a per-hour basis.

In order to see how fast individual fish called, we constructed histograms of the frequency of occurrence of number of boatwhistles in the 6-min segments (Figure 2). Even though the distributions for day and night were statistically different (Kolmogorov-Smirnoff test), they were combined in each of these histograms. Since these day-night differences have already been mentioned and were inconsistent between fish (Table 1), it seemed reasonable to present differences between the fish rather than differences between day and night.

Data from the three channels were combined to show the calling rate from all boatwhistles recorded in this study (Figure 3). It is obvious that toadfish remain quiet for long periods (Figure 1). For Figures 2 and 3, all quiet periods of 60 min or longer were arbitrarily excluded. Still, zeros accounted for close to 20% of all intervals measured (Figure 3). From the cumulative percent curve (Figure 3), it is striking how strongly the distribution is skewed toward the low end. Over 50% of the intervals measured had ≤ 1 to 2 boatwhistles/min (ca. 10 calls/6 min), and over 75% of the intervals had ≤4 to 5 boatwhistles/min. Only 10% of the intervals contained calls emitted at a rate of 6 or more per minute. Finally less than 1% of the intervals contained calls emitted at a rate of 10 to 12/min. Although an animal may have called for

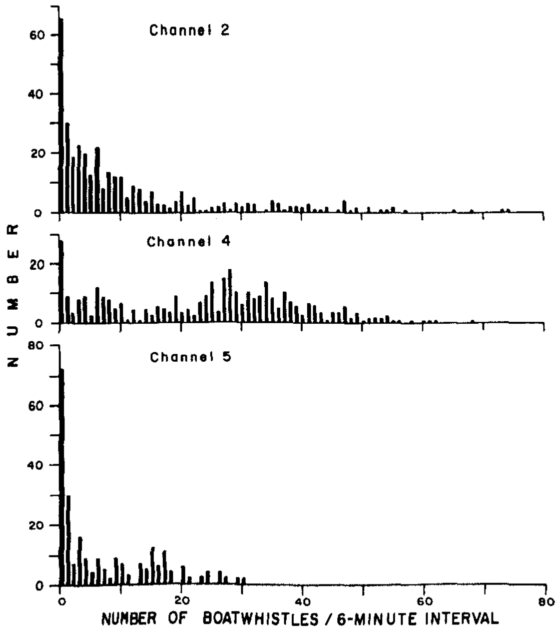

FIGURE 2.—Histogram of frequency of occurrence (i.e., "number" on Y-axis) of number of boatwhistles in 6-min intervals (X-axis) for each of three toadfish. Silent periods of an hour or longer were excluded from the analysis.

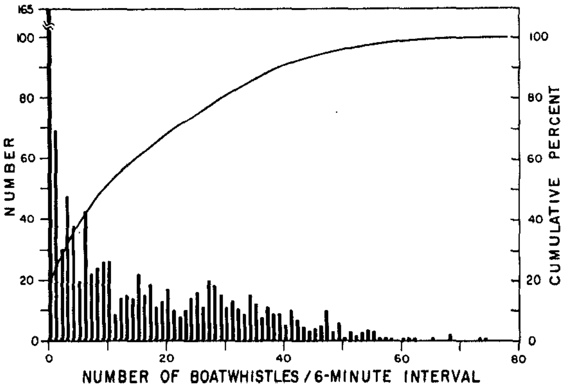

FIGURE 3.—Histogram of frequency of occurrence (left axis) and cumulative frequency of occurrence (right axis) of number of boatwhistles in 6-min intervals combined for the three toadfish. Silent periods of an hour or longer were excluded from the analysis.

many hours (Figure 1), the number of calls fluctuated markedly. High rates of calling were often strongly peaked, i.e., not maintained for long periods.

Discussion

The only obvious feature of the data from this study (Figure 1; Table 1) is its lack of patterning or predictability. Clearly, the recordings indicate no diel cycle. While they do not rule out the possibility of maximal or minimal periods of sound production for a toadfish population (Breder 1968), it appears unlikely that individuals would be synchronized to any great degree. It is difficult to reconcile these results with the periodicity of the in-air respiration data of Schwartz and Robinson (1963) and the impressions of Tavolga (1960) and Schwartz and Robinson (1963) that the toadfish is basically nocturnal. Squirrelfishes are active at night, when they are least vocal (Winn et al. 1964; Salmon 1967; Bright 1972; Bright and Sartori 1972), and likewise toadfish might not have a clear vocalization rhythm, while maintaining rhythms for respiration or other functions.

The rate of calling by fish in this study was low, and individuals lapsed into silence for long periods. This result verifies our experience from playback studies (Winn 1967, 1972; Fish 1972; Fish and Offutt 1972); fish were often silent, forcing us to sample many tiles to find a male calling rapidly enough for use in an experiment. For this reason preplayback calling rates, equivalent to control calling rates, were biased upward. From 68 experiments, each with sample sizes ranging between 11 and 16, Winn's (1972) preplayback data (recalculated) show a mean of 22.41 ± 4.3 (1 SD) boatwhistles/3 min, or an average of 7.5 calls/min. In his initial playback experiments, Winn (1967) increased the calling rate to an average of 11.46, 11.70, and 11.48 boatwhistles/min by playbacks of 18, 26, and 36 boatwhistles/min. Playbacks of 10 calls/min did not increase calling. Fish (1972) found that with optimally spaced playbacks, he could increase their rate to 14 to 16 sounds/min (1 call every 3.7 to 4.3 s). He called this pace the maximum sustained calling rate. Fish's data combined with Winn's indicate that when competing with other males, the toadfish does not grade his output uniformly, but follows more of a step function, i.e., his calling is either facilitated or not. In one chance encounter Fish (1972) observed a male calling 25 times/min as a female approached his shelter.

Our fish called considerably below their capabilities. However, calling rates of 11 and 12/min would suggest that the males were sexually receptive. It will take more work to establish what is normal for the toadfish and what abiotic and biological factors control motivation during the season. An unspawned male and a once-spawned male guarding eggs, might call at different rates. Schwartz (1974) and Lowe (1975) have indicated spawning peaks, which could be related to calling motivation. Although calling decreases, boatwhistles are still emitted after the assumed mating season (Fine 1976) It is not possible to accurately place the period of 9–15 June 1969 in a spawning peak or lull.

Density within a toadfish population will also affect sound production since calling fish facilitate each other. There could also be a tonic facilitation (Schleidt 1973), so that fish hearing boatwhistles, even if below the stimulatory rate, would be more prone to call than would a solitary male. It is also possible that some populations of toadfish could be limited by shelter availability for male nesting. At the dock at Solomons, where these recordings were made, shelter was provided primarily by our tiles placed along the dock pilings. Since the area was largely clear of rocks, tin cans, and boards which might provide shelter, the density of calling fish in the experimental area was not high, and we might not expect a great deal of facilitation.

Acknowledgments

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Literature Cited

BREDER, C. M., JR.
1968. Seasonal and diurnal occurrences of fish sounds in a small Florida Bay. Bull. Am. Mus. Nat. Hist. 138:327–378.
BRIGHT, T. J.
1972. Bio-acoustic studies on reef organisms. *In* B. B. Collette and S. A. Earle (editors), Results of the Tektite program: Ecology of coral reef fishes, p. 45–69. Bull. Nat. Hist. Mus. Los Ang. Cty. 14.
BRIGHT, T. J., AND J. D. SARTORI.
1972. Sound production by the reef fishes *Holocentrus coruscus, Holocentrus rufus,* and *Myripristis jacobus* family Holocentridae. Hydro-Lab J. 1:11-20.
FINE, M. L.
1976. Variation of natural and brain-stimulated sounds of the oyster toadfish *Opsanus tau* L. Ph.D. Thesis, Univ. Rhode Island, Kingston, 70 p.
FISH, J. F.
1972. The effect of sound playback on the toadfish. *In* H.E. Winn and B. L. Olla (editors), Behavior of marine animals: current perspectives in research. Vol. 2. Vertebrates, p. 386–434. Plenum Press, N.Y.
FISH, J. F., AND G. C. OFFUTT.
1972. Hearing thresholds from toadfish, *Opsanus tau,* measured in the laboratory and field. J. Acoust. Soc. Am. 51:1318–1321.
FISH, M. P.
1954. The character and significance of sound production among fishes of the western North Atlantic. Bull. Bingham. Oceanogr. Collect. Yale Univ. 14(3), 109 p.
GRAY, G. A., AND H. E. WINN.
1961. Reproduction ecology and sound production of the toadfish, *Opsanus tau.* Ecology 42:274–282.
LOWE, T. P.
1975. Reproductive ecology of oyster toadfish (*Opsanus tau*) in Charlestown Pond, Rhode Island. Ph.D. Thesis, Univ. Rhode Island, Kingston, 120 p.
SALMON, M.
1967. Acoustical behavior of the menpachi, *Myripristis berndti*, in Hawaii. Pac. Sci. 21:364-381.
SCHLEIDT, W. M.
1973. Tonic communication: continual effects of discrete signs in animal communication systems. J. Theor. Biol. 42:359–386.
SCHWARTZ, F. J.
1974. Movements of the oyster toadfish (Pisces: Batrachoididae) about Solomons, Maryland. Chesapeake Sci. 15:155–159.
SCHWARTZ, F. J., AND P. F. ROBINSON.
1963. Survival of exposed oyster toadfish and biological clocks. Prog. Fish-Cult. 25:151–154.
TAVOLGA, W. N.
1958. Underwater sounds produced by two species of toadfish, *Opsanus tau* and *Opsanus beta*. Bull. Mar. Sci. 8:278–284.
1960. Sound production and underwater communication in fishes. *In* W. E. Lanyon and W. N. Tavolga (editors), Animal sounds and communication, p. 93–136. Am. Inst. Biol. Sci. Publ. 7.
WINN, H. E.
1964. The biological significance of fish sounds. *In* W. N. Tavolga (editor), Marine bio-acoustics, p. 213–231. Pergamon Press, N.Y.
1967. Vocal facilitation and the biological significance of toadfish sounds. *In* W. N. Tavolga (editor), Marine bio-acoustics. Vol. 2, p. 283–304. Pergamon Press, N.Y.
1972. Acoustic discrimination by the toadfish with comments on signal systems. *In* H. E. Winn and B. L. Olla (editors), Behavior of marine animals: current perspectives in revol. 2. Vertebrates, p. 361–385. Plenum Press, N.Y.
WINN, H. E., J. A. MARSHALL, AND B. HAZLETT
1964. Behavior, diel activities, and stimuli that elicit sound production and reactions to sounds in the longspine squirrelfish. Copeia 1964:413–425.

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