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DEPTH DISTRIBUTION AND SEASONAL AND DIEL MOVEMENTS OF RATFISH, *HYDROLAGUS COLLIEI*, IN PUGET SOUND, WASHINGTON[1]

The ratfish, *Hydrolagus colliei*, inhabits the coastal waters of North America from Alaska to the Gulf of California (Hart 1973). One aspect of the biology of this species which has attracted attention is its vision physiology. It is generally accepted that most deepwater fish, regardless of phylogenetic position, have retinal pigments with maximum absorption at about 490 nm or less (Munz 1971; Lythgoe 1972). For example, *H. affinis*, the species of chimaeroid found in deep water of the western Atlantic, has retinal pigments with maximum absorbance at 477 nm (Denton and Nicol 1964). In contrast, a shallow-water species of chimaeroid (*Callorhinchus callorhynchus*) found off Chile has retinal pigments with

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maximum absorbance at 499 nm, a value which is typical of coastal fishes (McFarland 1970). Crescitelli (1969) and Beatty (1969), however, have reported that *H. colliei*, which can occur in water only 5 m deep, possesses retinal pigments characteristic of deepwater fish (λ_{max} = 484 nm). Crescitelli (1969) remarked that it is anomalous to find such pigments in a coastal species.

Like the retinal pigments, the structures for regulating the amount of light striking the retina in this species seem to be adapted to deep water. Maddock and Nicol (1978) found that the pupils of *H. colliei* cannot be contracted in bright light, and the reflective tapetum lucidum has no movable layer of dark pigments to eliminate eyeshine in bright light. While Stell[2] has found that there is an increase in pigmentation on the tapetum after full light adaptation, he estimated the degree of occulsion at 20% or less. Stell also indicated that ratfish appear to have an all-rod retina, a further adaptation to low light levels. In attempting to relate the spectral sensitivity of chimaeroid retinal pigments to depth of occurrence, Crescitelli (1969) and McFarland (1970) both noted that the absence of behavioral or ecological data on *H. colliei* makes it difficult to classify this species as an inhabitant of deep, shallow, or intermediate depths.

In the Gulf of California, *H. colliei* is typically captured below 275 m, although abundance varied seasonally (Matthews 1975). In other parts of its geographic range this species clearly inhabits shallower water. Jopson (1958) observed ratfish trapped in tide pools on the Oregon coast, and Dean (1906) reported catching them in about 4 m of water in Port Townsend Bay, Wash.

Recent studies have suggested that ratfish may undergo diel onshore migrations in Puget Sound. Miller et al.[3] reported trammel net catches of ratfish at night in areas where none were observed by scuba divers during the day. Moulton (1977) observed ratfish only in the evening and at night during dives on rocky reef sites. However, other divers (unpubl. obs.) have reported occasional sightings of ratfish in shallow water during the day.

[2]William K. Stell, Professor of Ophthalmology and Anatomy, Jules Stein Eye Institute, University of California, Los Angeles, Los Angeles, CA 90024, pers. commun. January 1978.

[3]Miller, B. S., C. A. Simenstad, and L. L. Moulton. 1976. Puget Sound baseline program: Nearshore fish survey. Unpubl. manuscr., 196 p. Univ. Wash., Fish. Res. Inst. FRI-UW-7604.

To further understand the relationship between visual systems and fish depth distribution, the present study was designed to focus on three questions. First, what is the overall bathymetric distribution of ratfish in Puget Sound? Second, to what extent do Puget Sound ratfish undergo seasonal and diel onshore migrations? Third, is there evidence for size- or sex-related patterns of abundance or movements?

Methods

Seven sites in central Puget Sound were sampled between 1965 and 1978: Port Madison, Port Gardner, Mukilteo, Duwamish Head, Point Pully, Alki Point, and West Point (Figure 1). Samples were obtained with a 6 m otter trawl and a 6 m beam trawl which we have previously found to fish with approximately the same results. All tows were on the bottom for 5 min.

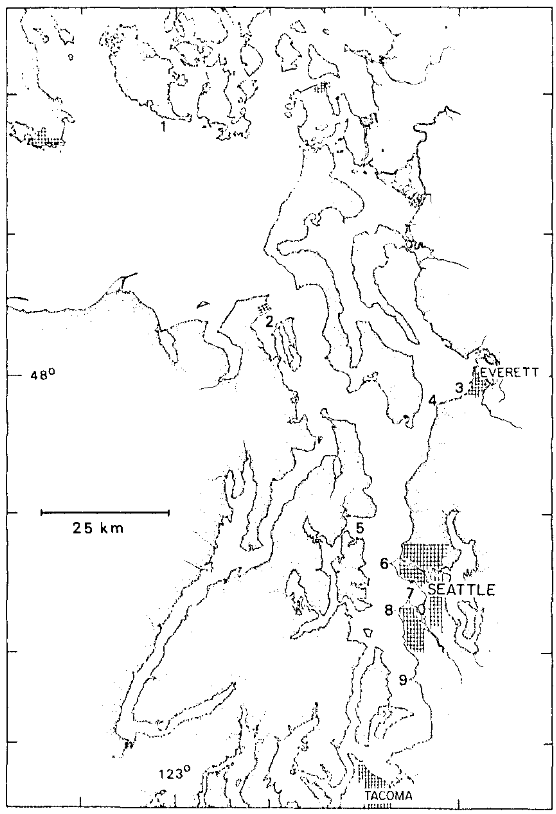

FIGURE 1.—Map of Puget Sound, Wash., with sites where ratfish were sampled. 1, Eagle Cove; 2, Port Townsend Bay; 3, Port Gardner; 4, Mukilteo; 5, Port Madison; 6, West Point; 7, Duwamish Head; 8, Alki Point; 9, Point Pully.

All sites were sampled during daylight hours about once a month. The depths sampled varied among the areas, but all sites were sampled at discrete depths between 10 and 70 m, several were sampled between 10 and 120 m, and one site between 5 and 150 m. When considering seasonal changes, winter was defined as January-March, spring as April-June, summer as July-September, and fall as October-December. Sampling effort was essentially the same at a given site and depth over all seasons.

Diel (24-h) studies were conducted at West Point in central Puget Sound (Figure 1) on 4 Nov. 1975, 13 Feb. 1976, 15 May 1976, 20 Aug. 1976, 19 Nov. 1976, and 5 May 1978. These six studies involved sampling at depths of 5, 15, 25, 35, 45, and 55 m every 4 h. The data were grouped into six time periods (Pacific standard time): 0400-0800, 0800-1200, 1200-1600, 1600-2000, 2000-2400, and 2400-0400 h.

In addition to the major sampling effort at the seven sites, a 24-h study was conducted at Eagle Cove (San Juan Island) in northern Puget Sound, and some daytime sampling was conducted in Port Townsend Bay (Figure 1).

All ratfish were counted, and length (measured to the end of the second dorsal fin), weight, and sex recorded.

Results

When all months were combined, data from the seven principal sampling sites indicated that ratfish were most abundant in the 55-95 m depth range. Hauls from depths <50 m and >100 m generally had a lower catch per unit effort of ratfish than those made at intermediate depths (Figure 2).

Port Townsend Bay was an exception to this pattern. Ratfish from this shallow-depth area (< 30 m) were sampled during June, August, and September 1978. In a total of 60 hauls at depths from 3 to 27 m, 182 ratfish were caught. This relatively high abundance of ratfish (3.03 fish/haul) in shallow water was in direct contrast to the scarcity of ratfish in <30 m at the other sites (1.31 fish/haul). (Actually, this latter average may be inflated by a few abundant hauls at Port Madison in the spring. If the Port Madison hauls are omitted, the average drops to 0.70 fish/haul). Not only was there an unusually large number of ratfish in shallow Port Townsend Bay, but the fish seemed to be selecting shallower water within the bay, because peak catches occurred in water only 10 m deep.

With the exception of the Port Townsend Bay samples, the basic depth distribution pattern was similar at the seven major sites. However, the pattern was subject to seasonal and diel variations. Catch per unit effort of ratfish was generally highest in spring, declined during summer and fall, and increased again in winter (Figure 3). This pattern was matched by a minimum average depth of capture in spring (70.5 m) and a maximum

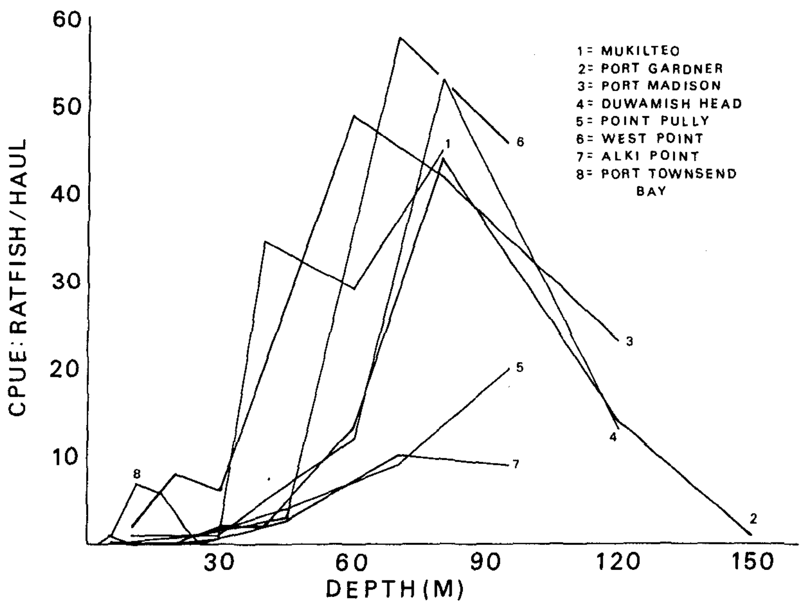

FIGURE 2.—Daytime depth distribution of ratfish at eight sites in Puget Sound, Wash., throughout the year.

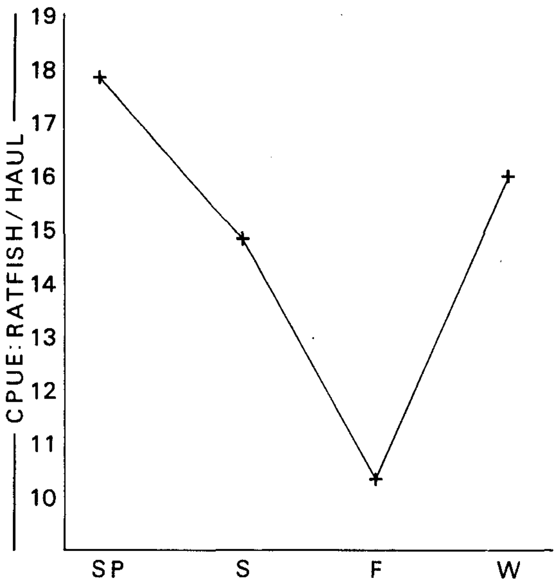

FIGURE 3.—Seasonal relationship between ratfish abundance (CPUE, catch per unit effort) in Puget Sound, Wash. (data averaged for the seven principal sites).

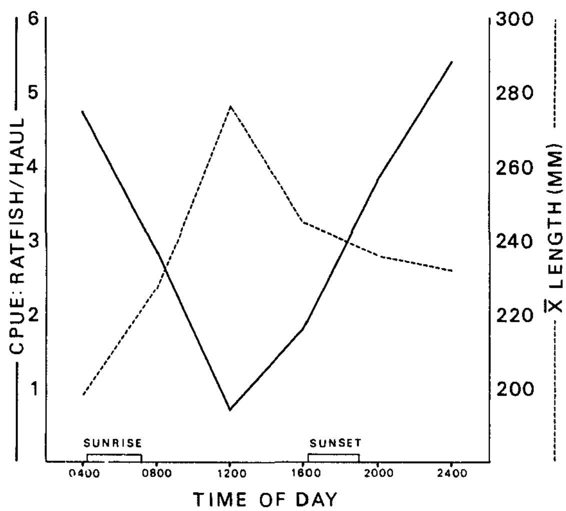

FIGURE 4.—Diel changes in abundance (CPUE, catch per unit effort) and average size of ratfish caught in shallow water (5-55 m) at West Point, Puget Sound, Wash.; data averaged from six 24-h studies.

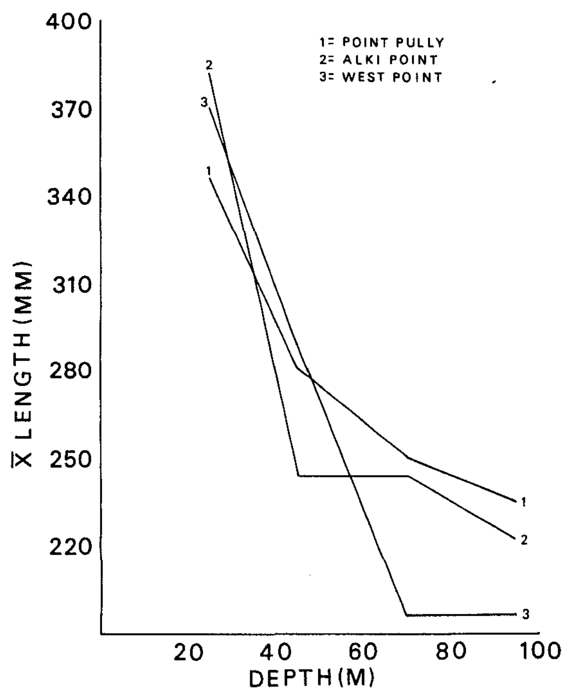

FIGURE 5.—Relationship between depth of capture and ratfish length in samples from three sites in Puget Sound, Wash.

average depth of capture in the fall (76.5 m). These two trends indicate that ratfish move shallower in the spring and deeper in the fall, perhaps beyond the sampling range of this study.

The 24-h studies gave evidence of a nocturnal, onshore movement. Within the sampling depths of 5-55 m, the number of fish per haul ranged from 0.69 in the 1200-1600 sample series to 5.42 in the 2400-0400 series (Figure 4). Although the samples were taken at different times of year, sunrise was always between 0415 and 0715 h, and sunset was between 1615 and 1930 h on the dates when the sampling was done. The data from the 24-h study at Eagle Cove also showed a peak in nearshore abundance after sunset and before sunrise, consistent with the West Point data.

The 24-h studies also provided evidence that large and small ratfish were not behaving alike. Although large fish were caught at night, there was a decrease in average length (Figure 4) indicating that the nocturnal onshore migration was composed principally of small fish.

Analysis of the combined monthly data from West Point, Alki Point, and Point Pully indicated that fish caught in shallow water were larger than those caught in deeper water (Figure 5). This trend was also apparent for the West Point 24-h and Port Townsend Bay data as well. The samples at Port Townsend Bay were from water <30 m deep, and the average length was 360 mm (±74 mm SD), and no ratfish were <200 mm long.

Sex ratios of ratfish at West Point, Alki Point, and Point Pully were significantly (chi-square) different from 1:1 ratio only in the spring, when 60% of the ratfish caught were females.

Discussion

In Puget Sound, the ratfish was most abundant from 55 to 99 m. While it should be noted that only three sites were sampled below 100 m, and none below 150 m, most of Puget Sound proper is shallower than 150 m. Still, the depth distribution of ratfish in central Puget Sound differs from that in the Gulf of California (Matthews 1975).

These southern ratfish were most abundant from 257 to 400 m. After noting a peak of abundance in February, Matthews (1975) speculated that the ratfish move into very deep water during the summer and fall, and return to shallower water in the winter and spring. This would be generally similar to the seasonal pattern of abundance observed at the Puget Sound sampling sites, where maximum abundance was in the spring (April-June); later in the year, the fish were in slightly deeper water.

While the differences in overall depth distribution of the Puget Sound and Gulf of California populations may be temperature related, and the seasonal movements may be related to reproduction, these factors do not seem to explain the diel movements of the Puget Sound population. One possible explanation for the nocturnal onshore movements of Puget Sound ratfish is that there is some food resource which is being exploited in shallow water. A study of ratfish food habits off the Oregon coast (Johnson and Horton 1972) found that 75% of the food items consumed were *Amphissa* sp., a gastropod mollusc. A study of ratfish food habits from Puget Sound indicates a much less specialized diet. Stomachs from 71 West Point ratfish contained a wide variety of items (Wingert et al.[4]). In general, smaller ratfish (<200 mm) fed principally on polychaetes, but stomachs of larger ratfish contained primarily bivalves, fish, and decapods. While some food items such as limpets and barnacles indicated shallow-water feeding, the sample size was not sufficient to establish the main feeding times or depths. Miller et al.[5] and Fresh et al.[6] also found wide prey spectra, with fish and polychaetes being the most important items. Ratfish seems to feed opportunistically on the most abundant, available items and will eat a wide range of crustaceans, molluscs, annelids, fish, echinoderms, and algae.

Whether or not the onshore movements are food-oriented, we still must explain why most of the small ratfish are found in deep water, and why they apparently approach shore primarily at night. One possible explanation is predator avoidance. The large, poisonous dorsal spine and large size probably make adults relatively safe from predation, but perhaps not juveniles. During the day, juveniles may tend to stay in deep water where their blue-shifted retinal pigment may give them an advantage over potential predators such as spiny dogfish, *Squalus acanthias* (Jones and Geen 1977).

The Puget Sound ratfish population is exploiting a nearshore niche. Its retinal pigment (chrysopsin) and eye morphology are similar to deep-sea chimaeroids, such as *H. affinis*, yet its depth distribution is comparable to many fish with retinal pigments located near 500 mm. By contrast, *C. callorhynchus* seems to be a more well-established coastal chimaeroid, having a typical coastal rhodopsin with peak absorbance at 499 mm (McFarland 1970). However, *H. colliei* has some adaptations to an environment with moderate light levels. Arnott and Nicol (1970) described the histological basis of the reflective skin of the species and explained this sheen as a camouflage device by which the reflected light would match the background illumination. The authors point out that this reflective sheen is typical of chimaeroids from moderate depths, such as *Chimaera monstrosa*, *C. cubana*, *C. phantasma*, and *Callorhinchus callorhynchus*, but that deep-sea members of the group, such as *H. affinis*, have dull-colored skin. Thus, *C. callorhynchus* seems to be well adapted to its nearshore habitat, *H. affinis* is adapted to its deep-sea habitat, and *H. colliei* is partly adapted to deep water and partly to shallow water.

While the visual system of *H. colliei* is clearly suited to the deep distribution exemplified by the Gulf of California population, it also seems com-

[4]Wingert, R. C., C. B. Terry, and B. S. Miller. 1979. Food and feeding habits of ecologically important nearshore and demersal fishes in central Puget Sound. Unpubl. manuscr., 83 p. Univ. Wash., Fish. Res. Inst. FRI-UW-7903.

[5]Miller, B. S., C. A. Simenstad, L. L. Moulton, K. L Fresh, F. C. Funk, W. A. Karp, and S. F. Borton. 1977. Puget Sound baseline program: Nearshore fish survey. Unpubl. manuscr., 220 p. Univ. Wash., Fish Res. Inst. FRI-UW-7710.

[6]Fresh, K. L., D. Rabin, C. A. Simenstad, E. O. Salo, K. Garrison, and L. Matheson. 1978. Fish ecology studies in the Nisqually Reach area of southern Puget Sound, Washington. Unpubl. manuscr., 151 p. Univ. Wash., Fish. Res. Inst. FRI-UW-7812.

patible with the distribution and behavior of Puget Sound ratfish.

While no quantitative measurements were made of light intensity or wavelength, to the human eye, the water in Puget Sound is quite dark at 25 m during the day, especially in winter. Considering that the fish is most abundant at about 75 m during the day and generally moves near shore only at night, McFarland's (1970) assessment that its retinal pigment might be appropriate for its depth distribution seems to be correct. Other aspects of its visual system, such as the apparently all-rod retina and nearly nonocclusible tapetum seem generally appropriate to its observed depth distribution. However, only more extensive studies of the feeding ecology, predators, and possible competitors of ratfish can explain why it moves onshore, why in some areas, such as Port Townsend Bay, it is found in shallow water during the day, and why in general it is found closer to shore in Puget Sound than in other areas in its range.

In summary, the data indicate that in Puget Sound, large ratfish predominate in shallow water, and smaller ones in deeper water. The species is most abundant in about 75 m of water, and tends to be in slightly shallower water in the spring and deeper water in the fall. Ratfish has a pronounced nocturnal onshore movement, which is composed primarily of smaller ratfish from deeper water.

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DETECTION OF PETROLEUM HYDROCARBONS BY THE DUNGENESS CRAB, *CANCER MAGISTER*

Behavioral responses that mitigate the effects of natural environmental perturbations may also be effective for contaminants from human activities, but the occurrence of any behavioral response, e.g., avoidance, first requires detection of the contaminant (Olla et al. 1980). To predict whether a behavioral response to a chemical pollutant will occur, one must ask whether the organism can detect the pollutant at concentrations likely to be encountered in field situations. Here we re-