Literature Cited

FAGERLUND, U. H. M., J. R. MCBRIDE, M. SMITH, AND N. TOMLINSON.
1963. Olfactory perception in migrating salmon. III. Stimulants for adult sockeye salmon (*Oncorhynchus nerka*) in home stream waters. J. Fish. Res. Board Can. 20:1457-1463.

HARA, T. J.
1970. An electrophysiological basis for olfactory discrimination in homing salmon: a review. J. Fish. Res. Board Can. 27:565-586.

HARA, T. J., K. UEDA, AND A. GORBMAN.
1965. Electroencephalographic studies of homing salmon. Science (Wash., D.C.) 149:884-885.

IDLER, D. R., J. R. MCBRIDE, R. E. E. JONAS, AND N. TOMLINSON.
1961. Olfactory perception in migrating salmon. II. Studies on a laboratory bio-assay for home-stream water and mammalian repellent. Can. J. Biochem. Physiol. 39:1575-1584.

OSHIMA, K., W. E. HAHN, AND A. GORBMAN.
1969. Olfactory discrimination of natural waters by salmon. J. Fish. Res. Board Can. 26:2111-2121.

SIEGEL, S.
1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, N.Y., 312 p.

SUTTERLIN, A. M., AND N. SUTTERLIN.
1971. Electrical responses of the olfactory epithelium of Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can. 28:565-572.

ANDREW E. DIZON

Southwest Fisheries Center
National Marine Fisheries Service, NOAA
P. O. Box 3830
Honolulu, HI 96812

ROSS M. HORRALL

Marine Studies Program
University of Wisconsin
Madison, WI 53706

ARTHUR D. HASLER

Laboratory of Limnology
University of Wisconsin
Madison, WI 53706

A TEMPORARILY ANOXIC WATER MASS IN AN ALASKA ESTUARY

Anoxic marine waters have been reported to exist in the Black Sea, in many fjords in Norway, in British Columbia, and in a few tropical basins (Richards, 1965a). Anoxic estuaries in nontropical areas are usually characterized by the existence of a very shallow sill that restricts horizontal water movement and a strong pycnocline that restricts vertical water movement. When these conditions exist, and a water mass below the biological compensation depth is not mixed with water above or outside of its basin, the dissolved oxygen is eventually depleted and remains so until there is an intrusion of oxygenated waters. An anoxic condition may be temporary where the isolation of the water mass is temporary. A fortuitous observation of temporary anoxia in Little Port Walter on southern Baranof Island, Alaska, in October 1971 suggests the possibility of other temporarily anoxic estuaries in Alaska. This is the first reported occurrence of a naturally anoxic estuary in Alaska.

Powers (1963) provides a detailed description of the physical and hydrographic features of the Little Port Walter estuary (Figure 1).

> The estuary is located near the [southern] tip of Baranof Island in southeastern Alaska. . . . A stream, Sashin Creek, enters the inner end over a small waterfall which marks the limit of salt-water intrusion. At its seaward end the estuary connects with Chatham Strait and Port Walter Bay . . . .
>
> The distance from the waterfall to Chatham Strait is 1.5 kilometers (km.); the distance across the widest part of the estuary is about 0.4 kilometer (km.). A peninsula . . . extends from the south shore and divides the estuary into two bays of approximately equal area, Inner Bay and Outer Bay. These are connected by a short channel . . . between [the peninsula] and the north shore.
>
> The maximum observed depth of Inner Bay was 21 meters (m.) and of Outer Bay, 44 m. (referred to mean lower low water). The depth of . . . [the channel], where a shallow sill is present, was almost 5 m. Because of this sill, Inner Bay has the structural characteristics of a fiord; Outer Bay does not, since it connects

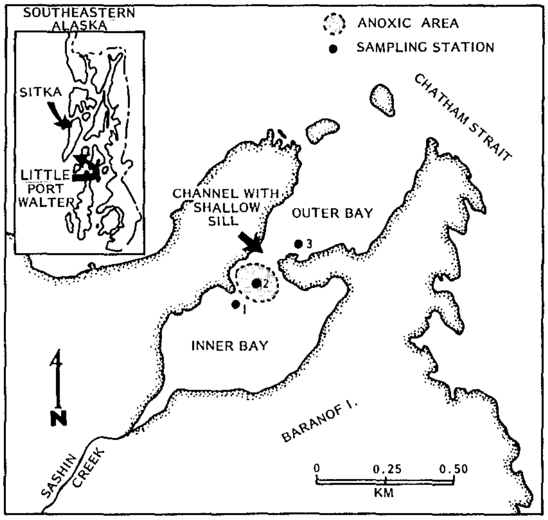

FIGURE 1.—Little Port Walter estuary, Baranof Island, southeastern Alaska.

directly with Chatham Strait through a channel approximately 36 m. deep.

The basins of both Inner and Outer Bays are steep sided, with practically no shelf formation except for a small shoal area at the head of Inner Bay. The surface area of the estuary consequently undergoes little change between low and high waters. Basins of this type are characteristic of Baranof Island as well as much of the rest of southeastern Alaska. The coastline is frequently indented by long narrow, deep embayments from which mountains rise sharply to heights of several thousand feet.

Tides in the estuary exhibit the exaggerated diurnal inequality typical of the west coast of North America. The range of spring tides at Little Port Walter is as much as 4.6 m., the range of neap tides less than half of this. Within the estuary, the tide has the characteristics of a standing wave, with high and low slack waters occurring at about the same time over the entire basin.

The surface area of Inner Bay, where the anoxic condition was observed, is about 0.25 km^2, and the approximate area of the affected water was about 0.02 km^2 (Figure 1).

Observations During Anoxic Period

The first time the anoxic condition was observed was on 4 October 1971, when two biologists (including the senior author) from the Auke Bay Fisheries Laboratory made a night dive in Inner Bay. The purpose of the dive was to count shrimp along underwater transects close to the shallow sill that separates Inner and Outer Bays. In a restricted area near the sill and below a depth of 12 m, the divers saw numerous dead animals on the bottom; most of them were shrimp, but there were also numerous chitons, limpets, clams, anemones, sea stars, crabs, and a few fish. No animals definitely known to be living were seen in the anoxic zone. No indication of the deeper affected zone was evident at the surface or in the water column at depths less than 12 m.

During the next 2 days (5 and 6 October) additional dives were made into the affected area to make more observations and to collect water samples. The water mass in the area of the die-off was obviously different from that in the rest of the bay; the water was milky, and visibility within the area ranged from a few centimeters to a meter. Outside of that area the water was clearer, and visibility was 6 m or more. Within the milky water of the die-off area, there was an odor of hydrogen sulfide—strong enough, in fact, to be smelled by the divers under water.

Three stations (Figure 1) were set up at which measurements of salinity, temperature, and dissolved oxygen were taken. Two of the stations were within the Inner Bay—station 2 in the affected area and station 1 in an unaffected area immediately adjacent to the affected water mass. The third station (station 3) was in the Outer Bay. Water samples collected on the third day of observations (6 October) in the area where the die-off had occurred had extremely low levels of dissolved oxygen (less than 0.08 to 0.45 mg O_2/liter); those collected outside of this area had much higher levels (4.23 to 8.29 mg O_2/liter). Approximate contours of distribution of dissolved oxygen are shown in Figure 2. The affected water mass had higher salinity than the surrounding waters within the Inner Bay; near the bottom salinity was 30.4‰ in the anoxic water and 30.1‰ in the adjacent oxygenated water (Figure 3). Similarly, temperature was higher in the anoxic water—9.2°C compared with 8.4° to 8.7°C in the adjacent oxygenated water in the Inner Bay (Figure 4). Calculated density values (Figure 5) show that the water within the affected mass was more dense (σ_t, 23.6) than the overriding water within the Inner Bay (σ_t, 22.6 to 23.4). The two features common to anoxic situations in fjords were present—a shallow sill and an adjacent pycnoline. The situation at Little Port Walter was typical of anoxic fjords; the pycnocline existed because of a strong halocline.

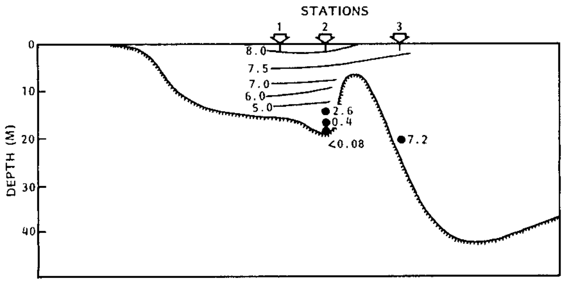

FIGURE 2.—Dissolved oxygen (mg/liter) contours in anoxic estuary, Inner Bay, Little Port Walter, 6 October 1971.

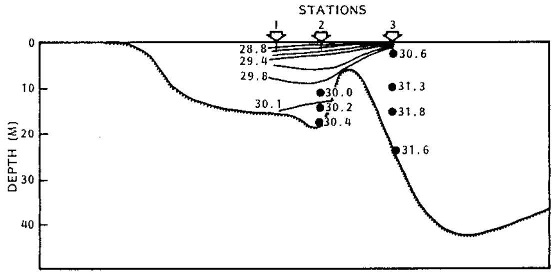

FIGURE 3.—Salinity (‰) contours in anoxic estuary, Inner Bay, Little Port Walter, 6 October 1971.

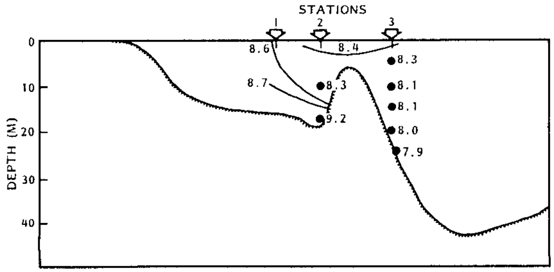

FIGURE 4.—Temperature (°C) contours in anoxic estuary, Inner Bay, Little Port Walter, 6 October 1971.

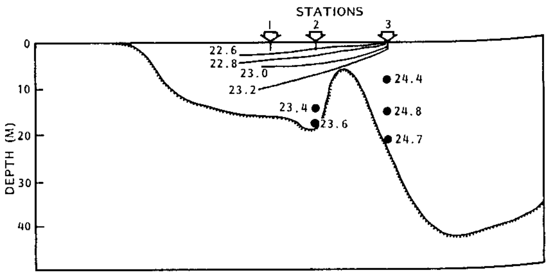

FIGURE 5.—Density (σ_t) contours in anoxic estuary, Inner Bay, Little Port Walter, 6 October 1971.

The mass of anoxic water was abruptly flushed out of the bay sometime between midday of 6 October and early evening of 7 October. On the evening of the 7th, divers found that the water was clear. Live benthic animals (mostly shrimp) were seen, although not abundantly, in the area where none had been seen the previous 3 days. Also, most of the dead organisms had disappeared.

Possible Causes of Formation and Destruction of Anoxic Condition

Depletion of dissolved oxygen to the point of anoxia in Little Port Walter is probably the result of the biochemical oxidation of organic matter (mainly salmon carcasses) both in Sashin Creek and in the Inner Bay. Richards (1965b) explains a mechanism which could account for the situation observed at Little Port Walter.

> As long as appreciable quantities of dissolved oxygen are present in the water, it is the preferred hydrogen acceptor for the biochemical oxidation of organic matter, being the richest available source of free energy. The decomposition can be pictured as the hydrolytic release of ammonium and phosphate ions, and the oxidation of the organic residues to carbon dioxide and water. The released ammonia is a transient form, because in oxygen-bearing waters it enters upon nitrification and is oxidized through nitrite to nitrate—the most abundant form of combined inorganic nitrogen in the ocean.
>
> When all, or nearly all, of the dissolved oxygen is consumed, nitrate and nitrite ions become the

> richest available source of free energy, and denitrification ensues. Again, phosphate and ammonium ions can be pictured as being hydrolytically released, and the organic residues are oxidized, by denitrifying bacteria, to carbon dioxide and water, with the concurrent reduction of nitrate and nitrite ions to free nitrogen. [The ammonia released during this process accumulates.]
>
> Following the disappearance of nitrate and nitrite ions, the next richest source of free energy in seawater is sulfate ions, which then take their place as hydrogen acceptors, being reduced to sulfides in the process. Again, phosphate and ammonium ions are hydrolytically released and accumulate while the organic residues are oxidized to carbon dioxide and water.

Brickell and Goering (1972) reported that on 29 September 1969, ammonia concentrations near the mouth of Sashin Creek were as high as 7.80 μg-atoms N/liter. This figure was 10 times higher than the concentrations in late August and early September before carcasses had begun to accumulate from the escapement of 30,000 pink salmon, *Oncorhynchus gorbuscha*. Dissolved organic nitrogen was at a peak concentration of 10.3 μg-atoms N/liter in the Inner Bay surface waters on 28 October—twice the concentration measured by Brickell and Goering in a control area lacking salmon carcasses. They did not report the presence of oxygen or sulfide, but their reported high levels of ammonia and dissolved organic nitrogen clearly indicate that chemical conditions were leading to sulfide formation at that time.

We did not measure ammonia and dissolved organic nitrogen in October 1971, but the escapement of 72,000 pink salmon, over twice that at the time of Brickell and Goering's study in 1969, would make the presence of excess ammonia and dissolved organic nitrogen even more likely in 1971. The detection of the odor of hydrogen sulfide by divers and in water samples implies that the reduction of organic materials had proceeded through oxidation and denitrification stages; i.e., in some parts of the water anoxic conditions were present.

The milky appearance of the water could have been due to the formation of colloidal sulfer when sulfide-bearing waters formed near the bottom mixed with oxygenated waters higher in the water column (Cline and Richards, 1969).

The sudden disappearance of the anoxic water from the bay was probably associated with extreme spring tides that immediately preceded the flushing. The large volume of exchange and relatively greater current velocities during the large tides probably caused a gradual reduction of the pycnocline. When the pycnocline was reduced sufficiently, mixing occurred throughout the water column, and the anoxic water was flushed out of the bay.

The coincident sudden disappearance of the dead organisms may have resulted from one or a combination of factors: use by scavengers such as amphipods, which moved back into the affected area after the flushing, or physical removal of many of the decaying organisms by water movements in the area.

Applicability of Observations of Anoxic Conditions

It seems probable that other estuaries in Alaska may also develop temporary anoxic conditions. Likely estuaries could be identified by studying the morphometry of the basin for presence of a shallow entrance sill and by determining the presence of periodically or chronically high biological oxygen demand. A capability for predicting formation of anoxic conditions in estuaries would aid in determining the proper management of susceptible bays which might be subjected to artificial introduction of large quantities of organic material.

Acknowledgments

Thanks are due to Robert J. Ellis, William R. Heard, and Roy Martin who assisted in the underwater observations and to Melford Bony who collected the water samples and oceanographic field data.

Literature Cited

BRICKELL, D. C., AND J. J. GOERING.
1972. Chemical effects of salmon decomposition on aquatic ecosystems. *In* R. S. Murphy and D. Nyquist (editors), International Symposium on

Water Pollution Control in Cold Climates, p. 125-138. U.S. Gov. Print. Off. Wash., D.C.

CLINE, J. D., AND F. A. RICHARDS.
1969. Oxygenation of hydrogen sulfide in seawater at constant salinity, temperature, and *p*H. Environ. Sci. Technol. 1969:838-843.

POWERS, C. F.
1963. Some aspects of the oceanography of Little Port Walter estuary, Baranof Island, Alaska. U.S. Fish Wildl. Serv., Fish. Bull. 63:143-164.

RICHARDS, F. A.
1965a. Anoxic basins and fjords. *In* J. P. Riley and G. Skirrow (editors), Chemical oceanography, Vol. I, p. 611-673. Academic Press, N.Y.
1965b. Chemical observations in some anoxic, sulfide-bearing basins and fjords. *In* Proceedings of the Second International Water Pollution Research Conference, p. 215-243. Pergamon Press, N.Y.

LOUIS BARR
JAMES R. KNULL

National Marine Fisheries Service
Auke Bay Fisheries Laboratory
Auke Bay, AK 99821

TARACTES RUBESCENS AND *TARACTICHTHYS STEINDACHNERI* FROM HAWAIIAN WATERS

The various species of the family Bramidae are mostly high-seas fishes with the possible exception of *Eumegistus*. Although capture records of adult *Taractes rubescens* (Jordan and Evermann, 1887) and *Taractichthys steindachneri* (Döderlein, 1883) are few, Mead (1972) surmises that they are probably widespread in the tropical oceanic Pacific. Most of the documented accounts of the occurrence of these two species in the Pacific Ocean are of juvenile stages taken from stomachs of large predators. In the Pacific, *Taractes rubescens* has been recorded from a few widely separated localities between lat. 05°48′N and 02°26′S and long. 88°46′ and 155°W. All except one of the documented captures are of juveniles smaller than 120 mm. The only adult specimen was taken by a Japanese longliner at lat. 05°48′N, long. 126°00′W. *Taractichthys steindachneri* is also known mostly from juveniles. They have been captured at widely separated localities between lat. 40° 48′N and 04°46′S and long. 165°35′W and 98° 28′E. Although adult specimens of this species are also taken incidentally by Japanese longliners, documented capture localities are available in the Pacific for only four specimens. This note records the capture of the adults of 10 *Taractes rubescens* and 2 *Taractichthys steindachneri* from Hawaii and also provides some observations on the ecology of the two species.

Within the area around the Hawaiian Islands bounded by lat. 10°-30°N and long. 150°-170°W, *Taractes rubescens* was previously known from one juvenile measuring 27.5 mm in standard length (SL) and *Taractichthys steindachneri* was known from three juveniles measuring 17.0, 42.5, and 130.0 mm SL (Mead, 1972). The latter species was also known from an adult specimen (*Taractes longipinnis* = *Taractichthys steindachneri*) "about 2 feet long" (Gosline and Brock, 1960). However, *T. steindachneri* is probably more common than indicated: Mead (1972) cites a personal communication from W. A. Gosline (December 1963) in which it is indicated that fishermen in Hawaii are familiar with this species. The 12 bramids reported here were captured on longline gear at nine fishing stations during cruise 101 of the NOAA vessel *Charles H. Gilbert* between 17 May and 6 June 1967 (Table 1). The fishing stations were from 14 to 30 km off the coast of Waianae, Oahu, over depths of 1,800-3,000 m. The surface water temperature ranged from 25.5° to 27.4°C and the salinity from 34.5‰ to 34.9‰ at the fishing stations. Other fishes caught together with the bramids, in order of abundance, were *Alepisaurus* sp., *Prionace glauca, Thunnus obesus, Tetrapturus audax, Xiphias gladius, Alopias* sp., *Gempylus serpens, Katsuwonus pelamis, Acanthocybium solandri, Thunnus albacares, Tetrapturus angustirostris*, and *Isurus* sp.

Three of the *Taractes rubescens* and both of the *Taractichthys steindachneri* were frozen after capture. Approximately 5 yr later, body measurements and counts on two *Taractes rubescens* and two *Taractichthys steindachneri* were made in the laboratory after the specimens thawed out (Table 2). The five preserved specimens are presently in the Southwest Fisheries Center, Honolulu Laboratory's fish collection.