natural mortality during the exploitation phase if natural mortality is significantly greater than fishing mortality. Even more drastically, recruitment to the exploitation phase varies inversely with the exponent of mortality rate before exploitation. (That is, each doubling of mortality can theoretically reduce yield to approximately one-seventh of what it otherwise would be.) Although such a simplistic view does not take into account the compensatory relations between predation, other sources of mortality, and growth, some of which may reduce the impact of natural predation in a real fishery, the potential effect is nonetheless striking.

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6. The complete regression equation is

$$Y = 48X_{\mathrm{SM}} - 1.8X^2_{\mathrm{SM}} + 50X_{\mathrm{L}} - 1.1X^2_{\mathrm{L}} + 10X_{\mathrm{E}} - 0.2X^2_{\mathrm{E}} + 110X_{\mathrm{H}} - 6.4X^2_{\mathrm{H}} - 23X_{\mathrm{SM}}X_{\mathrm{L}} - 2.2X_{\mathrm{L}}X_{\mathrm{H}} - 4.0X_{\mathrm{SM}}X_{\mathrm{SE}} - 8.0X_{\mathrm{H}}X_{\mathrm{SE}} - 1.0X_{\mathrm{L}}X_{\mathrm{E}} - 1.6X_{\mathrm{SM}}X_{\mathrm{E}}$$

All units are per mile of shoreline. Fishing gear is in terms of "canoe loads" (one seine, 40 gill nets, or 800 hooks per canoe). The equation was originally fitted separately to data from 1972 and 1973. As the 2 years gave almost identical results, they were pooled for the equation presented here. Negative square and cross-product terms reflect diminishing returns with higher fishing gear densities.

7. The optimum for Eq. 1 is no use at all of seines and small, intermediate, and extra large gill nets, accompanied by intensive use of hooks (4600 per mile) and large gill nets (660 per mile). The current average and maximum densities of hooks on Lake Victoria are 2000 and 3900 per mile, respectively. The current average and maximum densities of large gill nets are 160 and 645 per mile. Although the optimum is not very precise because of the numerous errors in the method, it should be valid for qualitative comparison with the present fishery.
8. Indulging in some ecological speculation, the larger species seem to deserve priority for optimal management because some of them (the tilapias) are herbivirous and have a high potential production per unit area, and others (the large predators) are mostly free of natural predation that would compete with predation by humans. The smaller species are primarily insectivorous and piscivorous predators at the end of long food chains and therefore lack the energy input to sustain heavy harvests by both humans and the larger predators.
9. The complete equations are

$$Y_{\mathrm{T}} = -4.8X_{\mathrm{SM}} + 6.2X_{\mathrm{L}} + 0.8X^2_{\mathrm{L}} + 8.8X_{\mathrm{E}} + 0.4X^2_{\mathrm{E}} + 29X_{\mathrm{H}} - 3.2X^2_{\mathrm{H}} - 0.7X^2_{\mathrm{SE}} - 2.0X_{\mathrm{E}}X_{\mathrm{L}} - 0.2X_{\mathrm{SM}}X_{\mathrm{L}} - 0.4X_{\mathrm{SM}}X_{\mathrm{SE}} - 0.4X_{\mathrm{E}}X_{\mathrm{SE}}$$

$$Y_{\mathrm{H}} = 21X_{\mathrm{SM}} - 1.0X^2_{\mathrm{SM}} - 9.6X_{\mathrm{M}} + 9.6X^2_{\mathrm{M}} - 20X_{\mathrm{E}} + 8.8X_{\mathrm{H}} - 0.26X^2_{\mathrm{H}} + 124X_{\mathrm{SE}} - 9.0X^2_{\mathrm{SE}} - 5.6X_{\mathrm{SM}}X_{\mathrm{SE}}$$

where X_{M} represents medium gill nets.

10. R. M. Chilvers and J. M. Gee, *J. Fish Biol.* **6**, 483 (1974).
11. The explanation for Fig. 2, presented in the text is based on predation, that is, causality from *Bagrus* to *Tilapia*. There are other possible explanations, including ones based on causality in the opposite direction. *Bagrus* is insectivorous until it reaches a length of approximately 15 cm and is piscivorous thereafter. It may be that in areas where *Tilapia* populations have been decimated by destructive fishing, more of the lake's primary production is channeled through food chains leading to aquatic insects, insectivorous fish, and eventually *Bagrus*. Such alternative explanations are not necessarily mutually exclusive.
12. G. G. Marten, B. Wanjala, R. Scully, J. N. Rinne, *Afr. J. Trop. Hydrobiol. Fish.*, in press.
13. Additional fishing effort might be directed by use of economic incentives. In any one region of the lake, one of the large predators is typically considered a delicacy and fished very heavily, whereas another is considered unfit for human consumption and remains underfished and very abundant. Which predator plays which role depends on tribal tastes in the region. If the infrastructure were available to market "trash" predators in areas where they are worth many times what they are locally, it should be possible to encourage heavy fishing of all the large predators.
14. This study was conducted under the auspices of the East African Freshwater Fisheries Research Organization (EAFFRO) with support from the U.S. Agency for International Development. Fisheries records were provided by the fisheries departments of Kenya, Tanzania, and Uganda. My EAFFRO colleagues J. Okedi, B. Wanjala, J. Rinne, L. Guluka, R. Scully, G. Ssentongo, and W. Kudhongania made numerous contributions. P. Larkin and H. Regier provided valuable comments on the manuscript.

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Carbon-13 Depletion in a Hydrothermal Vent Mussel: Suggestion of a Chemosynthetic Food Source

Abstract. *Tissues of a mytilid mussel from the Clambake I hydrothermal vent in the Galápagos Rift zone are strikingly depleted in carbon-13 relative to the tissues of other marine organisms. The stable carbon isotope composition of this mussel suggests that chemoautotrophic bacteria present in the hydrothermal waters are a major food source for filter-feeding organisms in this abyssal environment.*

Investigations of warm-water anomalies along the axis of the Galápagos Rift west of Equador led in 1977 to the unprecedented discovery of colonies of benthic marine organisms clustered around active hydrothermal vents (*1*, *2*). These abyssal communities include dense populations of clams, mussels, and other filter feeders which are found only in the immediate proximity of the vents. This profusion of filter feeders is thought to result from locally high fluxes of particulate organic matter (*2*). Possible ultimate sources of this food are (i) photosynthetically produced organic matter introduced from overlying waters and carried through the vent regions by convection currents near the ocean floor and (ii) sulfur-oxidizing bacteria and possibly other chemoautotrophs that are present in this sulfide-rich environment (*2*).

Limited evidence that marine chemoautotrophic bacteria fractionate carbon isotopes to a greater extent than marine phytoplankton (*3*) and general evidence for minimal fractionation of carbon isotopes along food chains (*4*–*6*) suggest that the distributions of stable carbon isotopes in the soft tissues of hydrothermal vent organisms might be used to discriminate between photosynthetic and chemosynthetic food sources. We report here a preliminary test of this hypothesis based upon carbon isotope analyses of tissues from a mytilid mussel collected at the Clambake I hydrothermal vent on the Galápagos Rift.

A mytilid mussel of unknown species 15 cm long was collected at a water depth of approximately 2500 m by the submersible *Alvin*. A specimen of *Mytilus californianus* 5 cm long from Freshwater Bay, Washington, and a specimen of *Mytilus edulis* 4 cm long from the Quiberon Peninsula of France were also analyzed. Entire specimens were frozen upon collection. Mantle and foot tissues were later excised and freeze-dried. Subsamples of 5 to 10 mg were taken from these tissues and combusted by the method of Buchanan and Corcoran (*7*). The resultant CO_2 was purified and isolated as described by Rau (*8*). The carbon isotope composition of the CO_2 was determined with a Nuclide 6-60 ratio

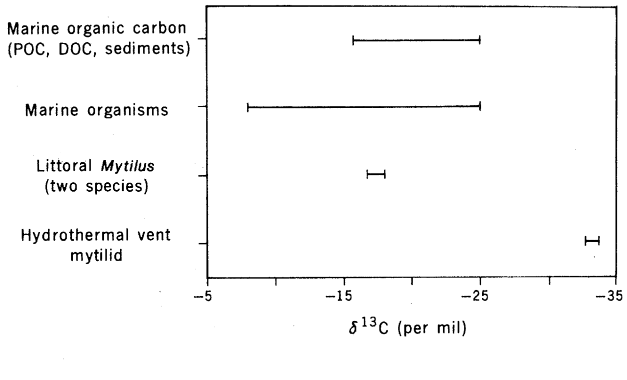

Fig. 1. The δ^{13}C of organisms and major organic carbon reservoirs in temperate ocean environments including pelagic and bathypelagic animals (*3*, *4*), particulate organic carbon (*POC*), dissolved organic carbon (*DOC*), and sediments (*4*, *5*). Also shown is the range of seven δ^{13}C determinations of foot and mantle tissues from two littoral *Mytilus* species and the range of eight determinations on the same types of tissue from a hydrothermal vent mytilid.

mass spectrometer and reported as δ^{13}C (*9*) with an analytical precision of approximately ± 0.2 per mil).

The δ^{13}C values of eight subsamples taken from the hydrothermal vent mussel tissues range from −32.7 to −33.6 per mil, with an average value of −33.2 per mil (Fig. 1). These values are strikingly lower than a compiled range of δ^{13}C from a wide variety of littoral, pelagic, and bathypelagic organisms from temperate oceans and also lower than values reported for major reservoirs of organic carbon in the marine environment including dissolved, particulate, and sedimentary organic matter (Fig. 1). The δ^{13}C values of the two *Mytilus* species from different littoral environments are within the range for marine organisms utilizing photosynthetically derived organic carbon (Fig. 1) and give no evidence that mytilid mussels fractionate carbon isotopes to an unusual extent. The lower relative abundance of ^{13}C in the tissues of the hydrothermal vent mussel by comparison with other marine organic carbon is thus evidence that the primary food source of this organism is not photosynthetically derived. This result supports suggestions by other investigators (*1*) that chemoautotrophic bacteria may be an important food source for the hydrothermal vent communities of the Galápagos Rift zone.

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9. $\delta^{13}\mathrm{C} = \{[(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{sample}}/(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{PDB}}] - 1\} \times 10^3$ per mil, where PDB is the Peedee belemnite standard.
10. We thank Drs. J. Corliss and J. Baross (Oregon State University) for providing the hydrothermal vent mussel and R. C. Clark for furnishing samples of *Mytilus* from the coast of France and the State of Washington. We also thank Dr. M. Stuiver for allowing us to use his isotope laboratory facilities at the University of Washington. Address correspondence to J.I.H.

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Seasonal Cycling of Cesium-137 in a Reservoir

Abstract. *Studies of a reservoir in the southeastern United States show that cesium-137, introduced into the system from a leak in a nuclear fuel element, cycles between the water and sediment on a seasonal basis. The cycling, which coincides with the annual periods of thermal stratification in this monomictic lake, has been occurring for over 10 years.*

Considerable research effort over the past several years has been devoted to determining the environmental chemistry of ^{137}Cs. Studies have shown that ^{137}Cs introduced into a watershed is attached to soil particles, which are removed by erosion and runoff (*1*). Some of the eroded soil particles comprise the sediments of the catchment basins in the watersheds and act as "sinks" for ^{137}Cs (*2*). Because of the high distribution coefficients of ^{137}Cs even in areas of differing soil-sediment type (*3*) and the almost irreversible fixation of this element in clay interlattice sites in freshwater environments, it is unlikely that this nuclide will be removed from these sediments under normal environmental conditions except by exposure to solutions of high ionic strength such as estuarine environments (*4*).

Thus far, all the studies of ^{137}Cs interaction with solids have been conducted either with tracer or fallout ^{137}Cs except for that of Simpson *et al.* (*5*) who dealt with low-level reactor releases in an estuarine system. The results of these studies have been extrapolated to predict the environmental fate of ^{137}Cs derived from the operation of nuclear reactors in freshwater systems. However, the release of low concentrations of ^{137}Cs from an experimental reactor fuel element at the Savannah River Plant, South Carolina, in 1957 has made it possible for us to study the environmental chemistry of this material during the intervening 12-year period and to compare it to that reported for ^{137}Cs from other sources.

Lower Three Runs Creek, on the site of the Savannah River Plant (Barnwell County) was dammed in 1958 to provide cooling water to two production reactors (P and R). The impoundment was completed in 1960 to form Par Pond (Fig. 1), an 1100-ha reservoir with a maximum depth of 16 m and a capacity of 6.8 × 10^{10} liters. Chemical and physical measurements of the system have been compiled regularly since 1965 (*6*). The pond is thermally stratified from April through October and well mixed from November through March. During thermal stratification, the hypolimnion becomes intensely anoxic with ferrous iron being dissolved from the sediment and in evidence throughout the hypolimnion. Concentrations of dissolved iron range from 0.02 part per million (ppm) in the epilimnion in the winter to more than 10 ppm in the hypolimnion during the height of stratification. The flux of iron from the sediments is so great during this stratification period that the concentration of dissolved iron in the surface waters increases about fourfold (*7*).

The R reactor area discharged small quantities of ^{137}Cs into the Par Pond system from 1954 until 1964 (*8*), due principally to the rupture of an experimental fuel element during testing in 1957. Initially the releases were to Lower Three Runs Creek until Par Pond was impounded in that portion of the watershed in 1958.

Studies of the ^{137}Cs concentration in Par Pond water have been carried on by three groups of researchers since 1960. The first studies were initiated by the Health Physics Environmental Monitoring Group at the Savannah River Plant. Cooling water pumped from Par Pond to the reactors has been monitored for ^{137}Cs. The pumping station's intake is located at a depth of 6 m, which is in the epilimnion of the pond. Water taken from the influent stream has been composited for a week to give a 1-liter total water sample which was analyzed for ^{137}Cs (*9*). The intake water has been monitored in that manner since 1960. In the second set of tests, from 1965 to 1968, J. S. Marshall sampled a station in the deepest area of the pond (Cold Dam station) on a monthly basis at depths of 1, 5, 10, and 15 m. These samples were analyzed for ^{137}Cs in cooperation with the Health Physics Group (*10*). Finally, during the period from March 1976 to February 1977 water samples were taken seasonally and with depth at the station occupied by Marshall in 1965 through 1968 and from two depths at a station in the bay of Par Pond (Hot Arm station) which currently receives thermal effluent (*11*).

The results of the monthly sampling from July 1965 through July 1968 demonstrate that ^{137}Cs concentrations in Par Pond water followed a seasonal cycle (Fig. 2). Elevated ^{137}Cs concentrations