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The Decline of the Chesapeake Bay Oyster Population: A Century of Habitat Destruction and Overfishing

by
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The Decline of The Chesapeake Bay Oyster Population: A Century of Habitat Destruction and Overfishing

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ABSTRACT

The oyster population in the Maryland portion of the Chesapeake Bay has declined by more than 30-fold since the early part of the century. The decline has been attributed to water quality and oyster disease. The decline has also been thought to have affected the biota and chemistry of the Bay. Our analysis shows that the declines are largely the result of overfishing early in the century, stock overfishing early in the century and during recent times, and that the major ecological effects on Chesapeake Bay occurred well-before World War II, before industrialization and the prevalence of disease.

A 38-fold decline in the Chesapeake Bay oyster (Crassostrea virginica) stock during the period 1884 to 1990 appears to have resulted from habitat loss caused by fishing, and stock overfishing both early in the century and in recent times (1).

The peak catch of oysters in Maryland was 615,000 metric tons in 1884 (Figure 1). This was the bulk of world production. The catch, which is correlated with the population abundance, declined almost steadily reaching a steady state in the 1920's of about 10^5 metric tons per year (the 1990-1991 catch is only about 16,000 metric tons). The decline occurred before water quality or oyster disease concerns were evident. Reenforcing the notion that the decline in catch reflected a decline in abundance was the 1900 observation that by the time that each dredging season (November 1 to March 15) was one-third over, the dredges practically exhausted the bars so that oyster reefs were worked many times in one season (2).

The decline in oyster abundance can be attributed in part to the destruction of oyster habitat in the Maryland portion of Chesapeake Bay. Before the turn of the century, fishing was prosecuted to only a limited extent and with gear that had only a marginal effect on the oyster reefs. As time progressed the absolute intensity of fishing and its areal extent increased dramatically. These effects were exacerbated as the fishing gear was changed from hand tongs which more or less "picked" oysters from the reef, to dredges and patent tongs which not only caught oysters, but destroyed the physical integrity of the oyster reef

structure. These structures had evolved as centuries-old accretions of oyster shells.

The decline in catch is associated with the destruction of oyster habitat in the Maryland portion of Chesapeake Bay by fishing which became more increasingly intensive and mechanized with time. From the mid-17th century to 1865, hand tongs, generally fished from small dorys and row boats, were the principal oyster fishing gear (3). About 3,275 hand-tong boats were operating in the late 1860's (3). After 1865 the use of large oyster dredges was legalized. The oyster dredge sweeps much more of an oyster reef than hand tongs (3), especially since they were used by large sail-powered vessels including sloops, schooners, and later the famous Chesapeake Bay skipjacks. In Maryland, by the late 1870's 700 dredge vessels were in the oyster fishery. By 1887, a gear capable of having a materially greater effect on the reefs was introduced, the hand-operated patent tong. The patent tong is like a jawed bucket. It is dropped to the bottom and when hauled back the jaws close removing a "bite" from the oyster-reef structure. The effects of the patent tong were intensified because at this time fishing boats began to utilize steam power, materially extending the range and fishing efficiency of the fleet, enabling it to fish previously unfished deep-water reefs. Attempts to constrain total fishing effort by restricting the dredge gear to only sail-powered vessels were of limited effectiveness because by 1890 the fleet of large sail-powered craft had increased to greater than 1000 vessels. In 1900 more than 5,714 dredges and 11,191 hand-tongs and

hand-operated patent tongs were operating in the oyster fishery (4). This amounted to a nominal 10 fold increase in dredge mortality and a fourfold increase in tong mortality. In 1950 the effects of the hand operated patent tong were intensified further by the introduction of the hydraulic powered patent-tongs. Continually declining catches in the hydraulic patent-tong and dredge fleets, stimulated diver harvesting of oysters in 1978.

The destruction of oyster bars can be assessed by analyzing data taken during c.1907 and c.1980 surveys which examined the areal extent of oyster habitat (5,6). In the 1907 Yates survey, boundaries of oyster bars were defined by triangulation. Samples were taken inside this boundary by hand-tongs to increase the resolution of the estimates of the areas of oyster habitat. In the 1980 MDNR survey, shelled areas were defined as oyster bars. The areal extent of these areas was measured by a variety of techniques. The two surveys were compared by superimposing the charts produced from each and then calculating the difference in bar area (BA) between the early 1900's and 1980's. Percent habitat change for each bar was calculated as: $[(BA_{1980} - BA_{1907})/BA_{1907}] \times 100\%$.

Figure 2 shows the frequency distribution of percent habitat reduction from the early part of the century to the present time classified by 1907 100-acre bar size-classes. The acreage of oyster bars has declined by more than 50 percent from 1907 to 1980. In addition to the substantial decline in acreage, the character of the bars must have been affected (7). When the European explorers first visited Chesapeake bay (circa 1600), reefs in shallow waters

were extensive and said to reach the surface (8). Some authors report that habitat diminution has continued even after 1980 (9).

The decline in habitat not only eliminates substrate but also likely affects the viability of the oyster. Natural oyster reefs form shoals rising several feet above the surrounding bottom, changing current patterns (10). Productive parts of the reef, where higher oyster growth occurs, show wake currents sufficiently strong so as to eliminate the effects of silting and self-silting (11). In addition, the living portion of a typical reef is generally thicker at the edges than in the center, where the turbid wake decreases while passing over the reef and thus suspended matter settles (11, 12). At the present time, the remaining productive bars are still located at areas with strong bathymetric gradients, areas where the highest tidal frictional turbulence is observed (13). Elsewhere in the bay, mechanical destruction of prime oyster beds by fishing has been exacerbated by environmental problems such as extensive sedimentation and erosion rates in the main productive areas (14). The habitat is now also subject to heavy siltation (15), probably due to simultaneous declines of water currents, turbulent mixing, and the oyster population. Increased concentrations of noxious particulate matter in the local vicinity of oysters has a deleterious effect on their filtration and assimilation rates, causes negative production, and decreases growth rates. Also, self-silting through bio-deposition production increases with higher particulate inorganic matter concentrations, induces energy loss and contributes to additional siltation (16).

These facts result in lower condition indices, reproductive efforts, and higher oyster mortality rates. Siltation is also responsible for the lack of suitable habitat for "spat" (recruiting juvenile oysters) settlement during the reproductive season (15). Because of the destruction of the physical structure and integrity of the bars oysters now live on significantly restricted reefs of diminished vertical profile, this deleteriously affecting oyster production capability. Such large changes in reef structure understandably affect other populations and may very well be related to the decline of the striped bass or rockfish.

In addition to the effect of fishing on habitat, the spawning-stock biomass and yield-per-recruit are at low levels because of the intensity of fishing, particularly on smaller oysters. Spawning-stock biomass and yield-per-recruit isopleths (17) are based upon estimates of: i) natural mortality, ii) growth, iii) length (largest dimension of shell length) and weight, iv) length and age at maturity, v) fishing mortality, and vi) the minimum length distribution of oysters taken by the fishing gear.

Natural mortality estimates are based on long-term studies (18) which agree with our own field observations suggesting that the instantaneous coefficient of natural mortality is about 0.15 (19). In terms of growth, it is surprising that there are virtually no data on oysters larger than 85 mm. Our observations and those of a number of authors (8,18,20,21,22,23) suggested that an oyster 85 mm in shell length is about three years old. It appears from our examination of 20,000 oysters that 150 mm in

length is a reasonable estimate of the average maximum length of an oyster (23). This results in the growth curve, L_t=150mm$(1-e^{-.28t})$ (25). Biomass can be obtained from length using the conversion $W_t=\alpha L_t^{\beta}$; where $\alpha=3.94\times10^{-4}$ and $\beta=2.80$, where weight at some age t is expressed in grams. The conversion was based on measuring approximately 17,000 oysters (26).

Size and age at maturity are used for computing the spawning stock biomass. According to Galtsoff (27) the size of sexual maturity is 31 mm or about one year of age. The oyster is evidently hermaphroditic and there may be a predominance of females at larger oyster sizes suggesting that high levels of fishing mortality affect the "natural" sex ratio of oysters.

Instantaneous fishing mortality rate is based upon estimates of total instantaneous mortality which is based on the average length (28). In 1890 the mean length of oysters in the catch was 73 mm (29). The size at first capture was 64 mm (2.5"). Using the growth curve, these lengths correspond to 2.5 and 2.1 years, respectively. The total instantaneous mortality rate based upon the reciprocal of the age difference was therefore 2.5. The instantaneous rate of fishing mortality is estimated at 2.35. In our 1990 survey the mean length was 88 mm and the size at first capture 76 mm. This corresponds to ages of 3.2 and 2.6 years, respectively. Total instantaneous mortality is therefore 1.7 and the fishing mortality is 1.6. So fishing mortality in recent years, although very high, is substantially lower than it was at the turn of the century. The smaller size at first capture at the

turn of the century and in 1990 was related to minimum size regulations. In response to general concern with declining oyster catches a 2.5" size limit was imposed in 1890 to conserve the resource. However, catches still continued to decline and the minimum was raised to 3.0" in 1927; it remains in effect today. Also note that prior to 1890 even smaller oysters may have been taken to supply the oyster seed fishery.

The computations above enable the computation of the yield-per-recruit and spawning-stock biomass isopleths (Figure 3). These show that early in the century and in 1990 high fishing mortality and the relatively low size at first capture reflects substantial overfishing. An increase in the size of first capture to 117 mm would result in roughly double the yield-per-recruit and quintuple the spawning stock biomass.

The effects of a diminished oyster population certainly must have had an effect on the ecology of Chesapeake Bay although these effects must have been evident at the time of the maximum stock decline in the 1920's, rather than in recent times (30). Effects at that time must have included the oysters reduced capacity to filter the water column (31), implying that increased quantities of dead phytoplankton which when settled to the bottom increased bacteria abundance. This led to significant portions of the bay becoming anoxic (32), a situation which again must have began well before World War II (33).

We conclude that there is substantial evidence that fishing has destroyed at least 50 percent of the oyster-reef habitat

inasmuch as there was once shell or other substrate where oysters could grow and the areas are now covered with silt and not suitable substrate for oysters. In addition there has been a history of stock overfishing. The stock overfishing may very well be related to recruitment overfishing (34,35). In this regard an increase in spawning stock biomass would compensate to some extent for the reduction in reef structure. It is interesting to observe that a 50 percent reduction in fishing mortality would not increase the oyster equilibrium yield-per-recruit, a fact of considerable economic significance to the management of the fishery.

Although considerable concern is voiced regarding Chesapeake Bay water quality and the effects of disease on oysters, fishing is a more likely culprit in the decline of the oyster even though the other effects may not be independent of fishing. A repletion program has been operated for a number of years, but we have shown that it is largely inefficient (20). Management measures to restore reefs de novo may not be cost-effective, but more targeted repletion combined with carefully regulated and managed fishing effort are likely to at least partially restore the reefs, important habitat for oysters, and associated species, such as blue crabs and rockfish.

REFERENCES AND NOTES

1. The decline in landings can be viewed as roughly proportional to landings from 615,000 metric tons in 1884 to 16,195 metric tons in 1989. Review of historical oyster production shows that the major decline began well prior to any significant outbreak of disease. Disease is associated with the effects of the protozoan parasites-- Haplosporidium nelsoni (MSX) and Perkinsus marinus (Dermo).

2. Grave, C. 1907. Shellfish Commission of Maryland. First Report, 231p.

3. Ingersoll, I. 1881. Census of the U.S. Department of the Interior:156-180; Winslow, F. 1881. Pop. Sci. Monthly 20:29-43 & 145-156.

4. U.S. Commission of Fisheries, Part XXVI. Commissioner's report 1900:268-287.

5. The Yates (6) survey was extensively conducted during the period 1906-1912, where 279,000 acres of natural oyster bar were surveyed and charted, representing 25% of the bay bottom. The MDNR survey used hydroaccoustics and bottom grabs for determining bottom sediment composition in the Maryland portion of the bay.

6. Yates, C.C. 1913. Summary of Survey of Oyster bars in Maryland, 1906-1913. Department of Commerce. 80p.

7. Winslow, F. 1881. Pop. Sci. Monthly 20:29-43 & 145-156; Whitcomb, J.P. and D.S. Haven. 1987. Virginia J. Shellfish Res. 6:55-65; Mackenzie, C.L. 1983. Marine Fisheries Review 45(3):1-22; Truitt, R.V. 1927. Annual. Rep. MD Conserv. Com., 5p; Hammer, R.C. 1948. Proc. Natl. Shellfish Assoc., 1947:8-10; Marshall, N. 1954. Proc. Natl. Shellfish Assoc., 44:113-122.

8. Kennedy V.S., Breisch L.L. 1983. Jour. of Envir. Managt. 16:153-171; Kennedy V.S. 1989. Marine invertebrate fisheries, their assessment and management. John Wiley & Sons, Inc.:455-477.

9. Seliger, H.H. and J.A. Boggs. 1988. Understanding the Estuary. Advances in Chesapeake Bay Research. CBP/TRS 24/88:111-127.

10. Chestnut, A.F. 1974. Coastal Ecological Ecosystems of the United States, Vol. II: 171-203; Dame, R.F. and B.C. Patten. 1981. Mar. Ecol. Prog. Ser. 5:115-124.; Grave, C. 1905. Report of the U.S. Commission of Fish and Fisheries for

1903:247-351; Copeland, B.J. and H.J. Hoese. 1966. Publication Inst. Mar. Sci., Univ. Texas 11:149-158.

11. Lund, E.J. 1957. Publ. Inst. Mar. Sci. Texas:320-327.

12. Bahr, L.M. 1976. Ecology 57:121-131.

13. Seliger, H.H. and J.A. Boggs. 1988. Understanding the Estuary: Advances in Chesapeake Bay Research. CBP/TRS 24/88:111-127.

14. Hill, J.M. 1988. Maryland Geological Survey, Report of Investigations; 49, 32p.

15. Schubel J.R. 1972. Jour. of the Wash. Acad. of Sciences. 62(2):56-87; Mackenzie, C.L. 1983. Marine Fisheries Review 45(3):1-22; Mackenzie, C.L. 1989. Marine Fisheries Review 51(3):1-47; Bahr, L.M. 1976. Ecology, 57:121-131.

16. Loosanof, V.L. and F.D. Tommers. 1948. Science 107(2768):69-70; Héral, M., Deslous-Paoli, J.M., and J.M. Sornin. 1983. Oceanis 9(3):169-194; Lund, E.J. 1957. Publ. Inst. Mar. Sci. Texas:320-327; Winter, J.E. 1978. Aquaculture 13:1-33; Bahr, L.M. 1976. Ecology 57:121-131.

17. Beverton, R.J.H. and S.J. Holt. 1957. Fish. Invest. Minist. Agric. Fish. Food UK (Series 2), 19. 533p.

18. Abbe, G. 1987. Ecological studies in the Middle Reach of Chesapeake Bay. Springer Verlag.:142-164.

19. Several investigators (18,20,22) have held various size classes of small (<100 mm) oysters over time in containers and estimated the cohort survivorship. We estimated M=0.15 and this is roughly the average of other studies.

20. Rothschild, B.J. et al. 1990. UMCEES[CBL] 90-131. 258p.

21. Kent, B.W. 1988. Making dead oysters talk. Maryland Historical Department. 107p; Webster, J.R. 1953. Proc. Natl. Shellfish. Assoc. 1952:113-120; Goode, G.B. 1884. U.S. Commission of fish and fisheries. The fishery industry of the United States, 895p.

22. Beaven, G.F. 1950. Proc. Natl. Shellfish. Assoc. 1949:43-49; Beaven, G.F. 1953. Proc. Natl. Shellfish Assoc. 43:90-98; Butler, P.A. 1953. Proc. Natl. Shellfish. Assoc. 43:157-162; McHugh, J.L. and Andrews, J.D. 1955. Proc. Natl. Shellfish. Assoc. 45:217-239; Shaw, W.N. 1966. Proc. Gulf Carib. Fish. Inst. 19:108-115; Shaw, W.N. 1966. Proc. Natl. Shellfish. Assoc. 56:59-63; Shaw, W.N. and Merrill, A.S. 1966. Proc. Natl. Shellfish. Assoc. 56:67-72; Kennedy V.S. and Breisch L.L. 1981. Sea Grant Program Publi. UM-SG TS. 81-04. Univ.

of Maryland. 286p; Prou J., Goulletquer P., Bacher C. 1991. CBL-IFREMER Report, 20p.

23. Goode and archeological observations of Indian midden sites around the Chesapeake Bay have uncovered shells of up to 200-230 mm length (21), suggesting that L_∞ may have been larger in the past. Our own field work has found living oysters of up to 185 mm. Some work suggests that animals growing at higher densities and on soft bottoms tend to extend their growth in shell length rather than putting on shell depth and greater weight per unit of surface area (Krantz, pers. com., 21, 22, 24).

24. Caddy, J.F. 1989. Marine Invertebrate Fisheries:665-700.

25. The coefficient K of the von Bertalanffy growth model can be estimated from solving simultaneous equations between two constrained points corresponding to the age and lengths at time zero and some older age λ yielding $K=1/(t_\lambda-t_0)\ln[(L_\infty-L_0)/(L_\infty-L_\lambda)]$. Thus, K was estimated as $K=[1/3]\ln[150/(150-85)]=0.28$.

26. Conversion of the growth curve to weight-at-age is accomplished by inserting L_∞ for L_t in $W_\infty=\alpha L_\infty^\beta$ and expanding the growth curve to the power β. Biomass-at-age is computed as $B_t=N_tW_t$ and then sum across all ages for population biomass B. Yield in weight Y_w is assumed proportional to population biomass as $Y_w=FB$, where fishing mortality F is the proportionality constant.

27. Galtsoff, P.S. 1964. Fish Bull. 64:480p.

28. Ehrhardt, N.M. and J.S. Ault. 1991. Trans. Am. Fish. Soc. (submitted)

29. Brooks, W.K. 1905. The Oyster. John Hopkins Press. 255p.

30. Seliger H.H. and J.A. Boggs. 1988. Understanding the Estuary: Advances in Chesapeake Bay Research. CBP/TRS 24/88:570-583.

31. Newell, R.I.E. 1988. Understanding the Estuary. Advances in Chesapeake Bay Research. CBP/TRS 24/88:536-546.

32. Kemp, W.P. and W.R. Boynton. 1984. Bull. Mar. Sci. 35:242-247.

33. Newcombe, C.L. and W.A. Horne. 1938. Science 88:80.

34. Rothschild, B.J. 1986. Dynamics of Marine Fish Populations. Harvard. 277p.

35. There are two distinct reasons for fishery decline that can apply individually or in combination. Recruitment overfishing

has been associated with falling catches resulting from heavy fishing because the spawning stock biomass is reduced to too low a level to ensure adequate production of young oysters, the recruits to the future fishery (36). Growth overfishing is where oysters are being caught so young that they are not being given a chance to grow to a decent size (37). Though increased fishing intensity will increase the number of oysters caught (that is above the present levels), their average weight will steadily decrease, and so, ultimately, will the total weight of the catch.

36. Gulland, J.A. 1983. Fish Stock Assessment: A Manual of Basic Methods. Wiley.

37. Cushing, D.H. 1972. Proc. R. Soc. Edinb. (B) 73(36):361-390.

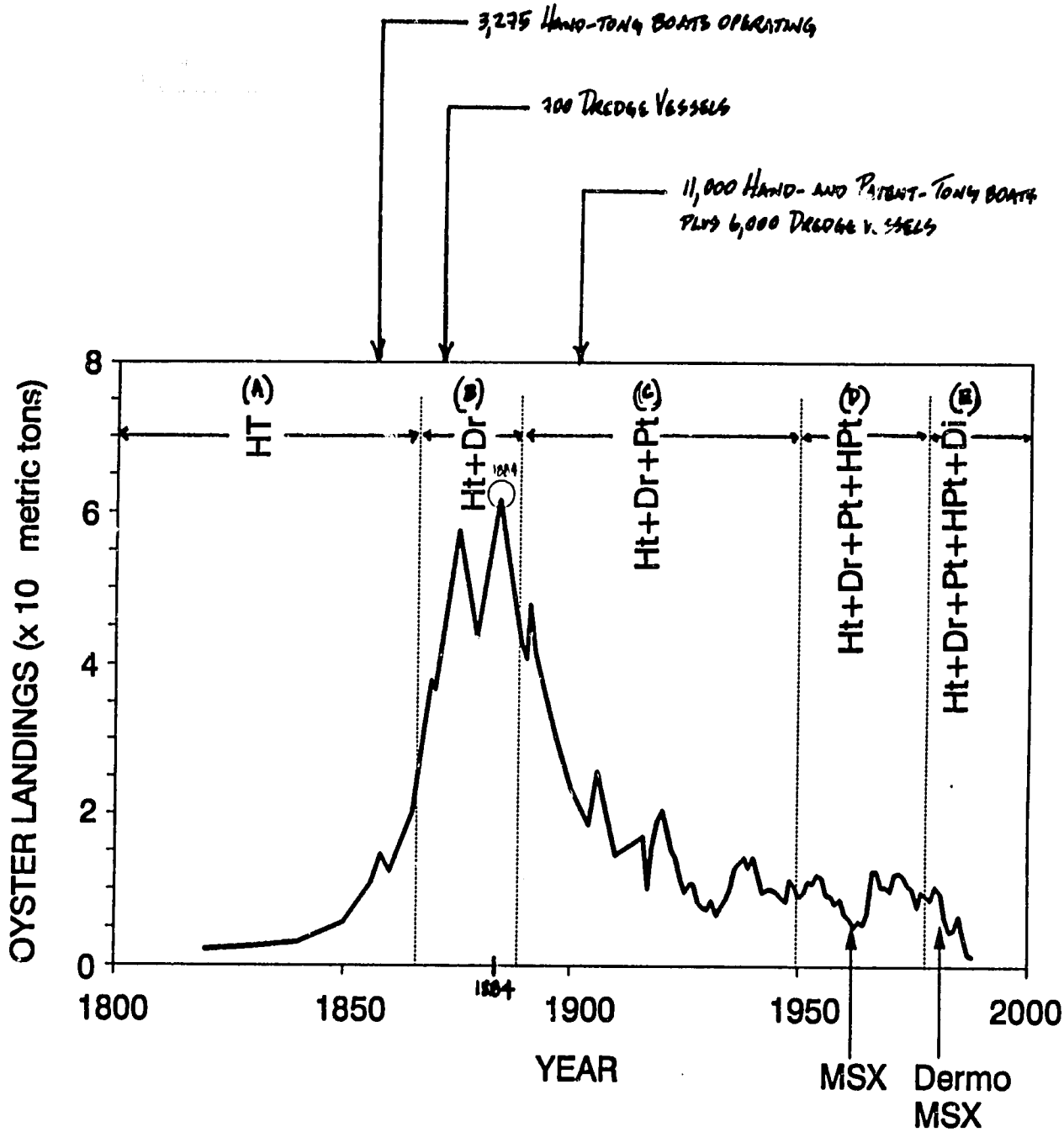

Figure 1: Time series of Maryland oyster landings. The panel segments show corresponding evolution of the fishing gears: (A) use of hand tongs (HT), (b) introduction of dredges (DR) (note peak in production occurred in 1884), (C) introduction of patent tongs (PT) which corresponds with the beginning of the catch decline, (D) introduction of the hydraulic patent tong (HPT) in 1950, (E) the addition of diver harvesting (DI) in 1980.

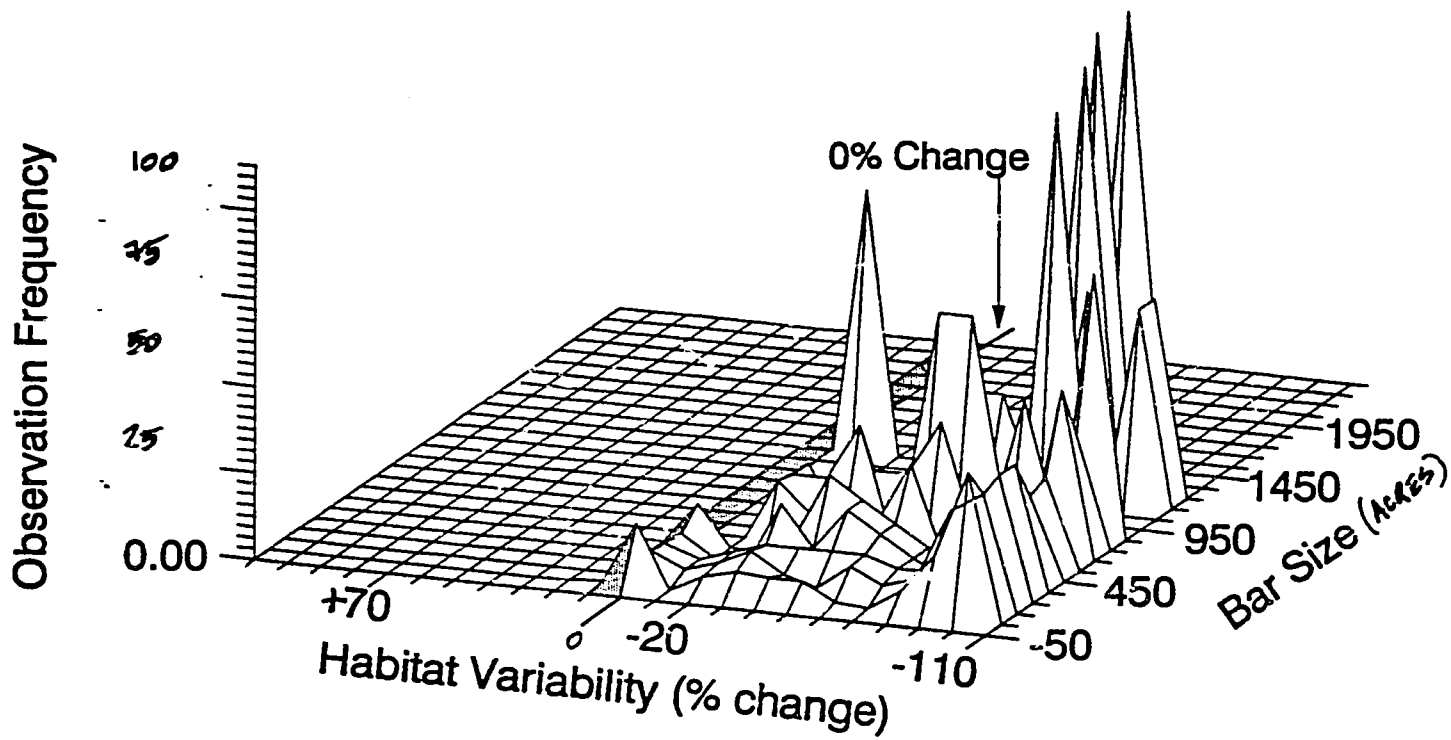

Figure 2: Percent loss of oyster reefs in the Maryland portion of the Chesapeake Bay determined by comparison of the 1907 survey of Yates (5,6) to the 1980 Maryland Department of Natural Resources bay bottom survey (5). The gray stippled region represents the line of zero change in bar habitat area between the two surveys.

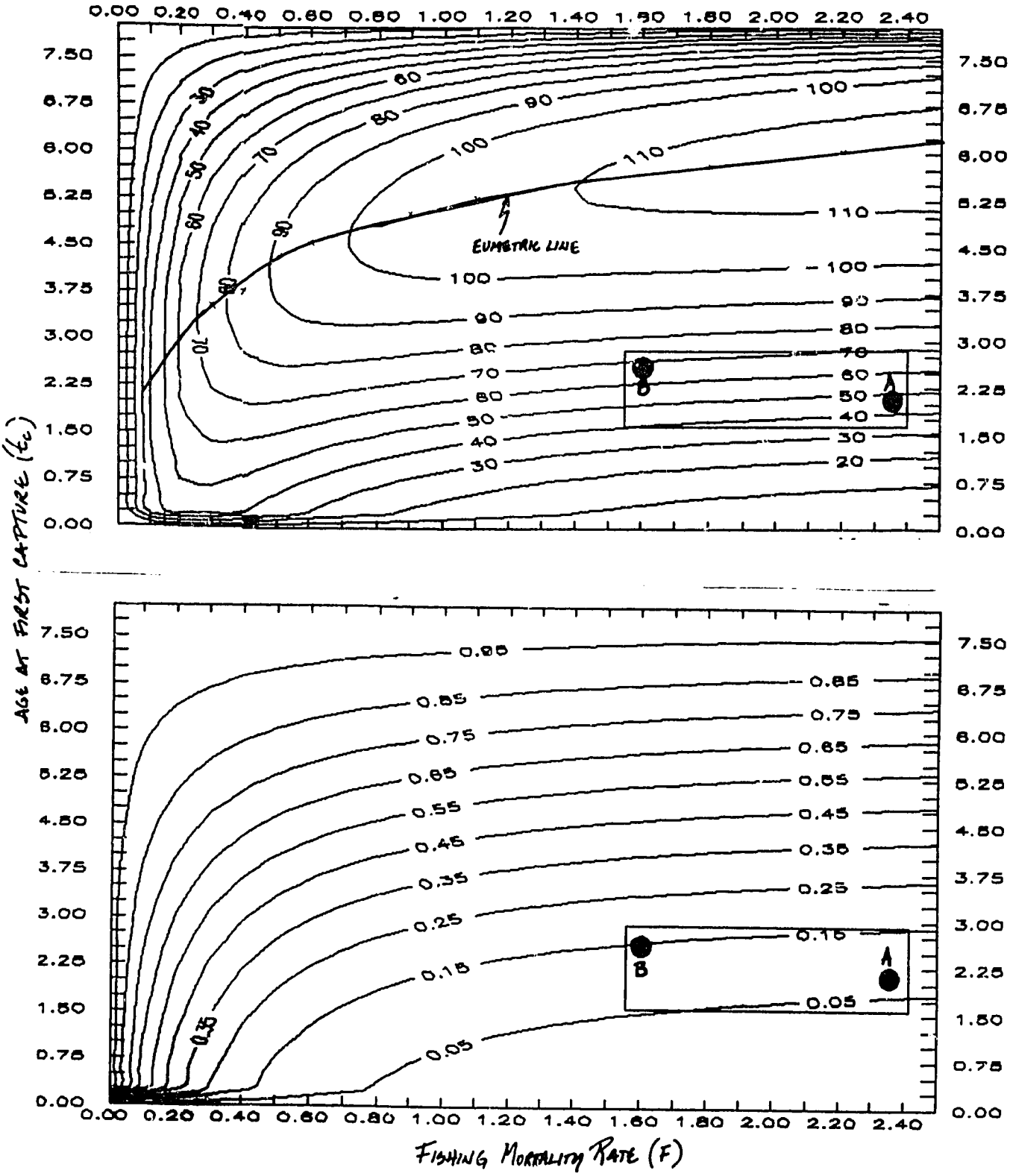

Figure 3: Yield-per-recruit and spawning stock biomass isopleths expressed as functions of fishing mortality rate F and age of first capture t_c for the Chesapeake Bay Oyster stock. Spawning stock biomass is expressed as a fraction of the unexploited stock (i.e. fishing mortality rate equals zero). Point A shows roughly the 1900 position of the fishery, and B shows roughly the 1990 position. The rectangular area shows the range of the fishery over the last century. Parameters for generation of the isopleths were: M=0.15, W_∞=488.5 grams, K=0.28 yr^{-1}, t_m=0.92 years.