Indirect Effects: Environmental Changes, Copepods and Herring

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Introduction

Cherry Point (CP) herring once had a spawning biomass equal to all other herring stocks in the state combined. The CP herring population declined steadily from 15,000 tons in 1973 to 800 tons in 2000. Mortality in older age classes resulted in a recruit-dominated age structure. Recruitment (the amount of first time spawners) was good during much of the period of decline in stock size. The average annual recruitment from 1974 to 1995 was 2121 tons. 1994 had a record recruitment of 4076 tons. The proportion of recruits in the population from 1985 to 2000 was usually above 0.5 with a maximum above 0.7. Recruitment dropped in 1996 and averaged 755 tons from 1996 to 2000 causing the population decline to worsen. The US government is currently considering a petition to list the CP stock of herring under the Endangered Species Act.

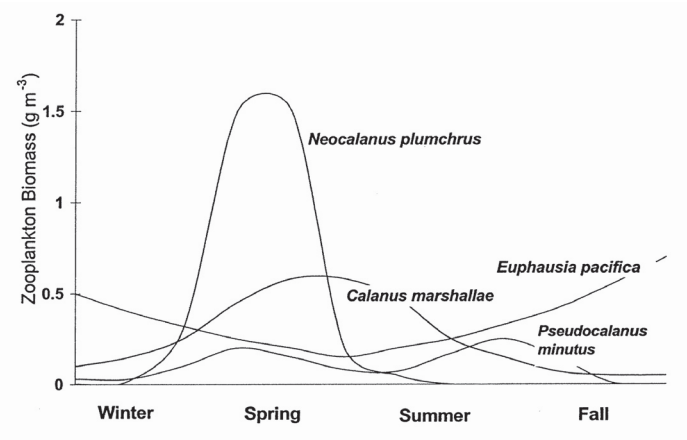
The pace of the decline focused attention on potential causes such as pollution sources, predators, and the CP herring themselves. Two oil refineries and an aluminum smelter are located along the shoreline used for spawning. Outplants of herring embryos at some shoreline stations produced greater numbers of impaired larvae relative to other stations and laboratory controls. Because of concern over the declining population size, environmental permits and leases have become more difficult to issue and expensive to implement. Two risk assessments were conducted. The unusually late spawning season (April to early June) of the CP herring was considered as a factor in their decline. Mackerel, hake, and harbor seals have also been considered as factors in the decline. Herring toxicity tests are being developed. Despite extensive investigations, no clear cause of the decline could be determined. Recently we have begun looking into other causes such as changes in availability of food for herring. This latter approach appears to offer new insight into the causes of the CP herring decline.

Materials and Methods

The Pacific Region Zooplankton Database of the Institute of Ocean Sciences (IOS) of the Department of Fisheries and Oceans Canada was queried for data from two stations (CPF1 and CPF2) in the Strait of Georgia (SOG). The mean annual calanoid copepod abundance (number/m^3) and biomass (mg dry weight/m^3) were calculated. Comparisons were made to CP herring stock assessment data. Because no data from earlier than 1991 were available in the database for these stations, the scientific literature was surveyed for relevant historical data concerning copepods and herring. The percentages of abnormal herring larvae from embryo outplants at shoreline stations were averaged, ranked by station, and compared to CP herring spawning behavior.

Results And Discussion

It was discovered in the 1920s that the zooplankton biomass of the upper layer of the SOG peaks in April through early June and is dominated by one species, *Neocalanus plumchrus*. These *N. plumchrus* are present near the surface of the SOG for a relatively brief (70-100 days) period of time after which they descend below 300 m. 90% to 100% of the stomach contents of adult herring captured in surface trawls around the SOG in the spring of 1966 were *N. plumchrus* if it was also found in concurrent zooplankton tows (Barraclough and Fulton, 1967). CP herring spawning coincides with the emergence of *N. plumchrus* copepodites near the surface. *N. plumchrus* overwhelmingly dominated the zooplankton biomass of the SOG in spring during the 1960s when the CP population was large (Parsons et al., 1970).



Seasonal changes in biomass of dominant zooplankton species inhabiting the upper 20-50 m of the water column of the Strait of Georgia. (redrawn from Harrison *et al.* 1983)

Gardner (1976) reported a sharp decline in the SOG *N. plumchrus* population beginning in 1971 and predicted declines in fish populations due to the greater energy needed to acquire the same amount of nutrition from smaller copepods compared to the much larger *N. plumchrus*. CP herring spawn later than other regional herring and delay resumption of full-time feeding for a longer period of time. Adult herring must feed and begin rebuilding fat reserves soon after spawning and may time spawning to account for this need as well as the need for larval food (Quast, 1986). Energy demand for gonad recrudescence increases with age because of an increasing ratio of gonadal to somatic body mass, resulting in greater starvation rates for older herring (Quast, 1986). These factors can account for the age-related mortality in the CP herring population.

The IOS data show an unusually large abundance and biomass of small calanoid copepods in 1993, which coincides with excellent recruitment at CP that year and a record recruitment the next year. The IOS database shows a return to abundance of *N. plumchrus* by 1998, and the mean biomass of calanoid copepods at CPF1 and CPF2 declined in 1998–2001 relative to 1991-1995 as *N. plumchrus* returned to dominance in the spring

and began carrying more of the SOG biomass down into deep water where it was unlikely to be encountered in any plankton tows for the remainder of the year. This decline in biomass of smaller copepods approximately coincided with the drop in CP herring recruitment. CP herring have produced modest population increases each year from 2001 to 2004 and adult survival seems to have improved. 1996 and 1997 zooplankton data are unfortunately unavailable.

Percentages of abnormal larvae were averaged for the 4 years (1990, 1991, 1992, and 1998) of herring embryo outplants at 12 standardized stations (Hershberger and Kocan, 1999). The percent abnormal ranged from 54.3% at the worst station to 25.4% at the best station. Stations that are adjacent along the shoreline tend to also be adjacent in a ranking of percent abnormal. The four best stations and four worst stations represent geographical groupings and the difference between the group means is statistically significant at *alpha* = 0.05. During the time of this study, CP herring only spawned near the best four stations. Recruitment in the early 1990s was very good, but the biomass of small calanoid copepods was large and CP herring were spawning along the shoreline where the embryo outplants developed best.

Conclusions

- Fish population numbers alone are not adequate for risk management decisions.
- Mysteries can be solved. Existing information suggests explanations for the late spawning time, population decline, record 1994 recruitment, etc.
- Nature works on a long time scale. Older publications in biology are gold to be mined.
- No population can be understood except in relation to its food and predators. Copepods are diatoms on their way to becoming herring. Herring are copepods on their way to becoming salmon. Add nutrients and sunlight to water and it is set in motion.
- A thorough understanding will only come from maintaining a consistently high level of effort in observing the ecosystem at all trophic levels, better communication between biologists studying different taxa, and paying no more attention to the national border than the herring do.
- The Strait of Georgia's semi-isolated condition and relatively small scale make it a natural laboratory that is invaluable for what it can show about marine ecosystems and productivity. It is also exposed to multiple environmental risks due the nearby human population centers. These are excellent reasons for a consistently high level of study effort.
- Misunderstandings and mysteries can be expensive when circumstances demand risk management decisions.
- Older publications from the Washington Department of Fisheries indicate that the CP population may have undergone similar declines in abundance in previous decades. If this is a natural and recurring population cycle with copepods as an important factor, the spawning grounds need to be preserved so that recruits are available for population maintenance or rebuilding at critical points in the population cycle.

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Species-Specific Responses to Environmental Contaminants: A Case for Comparative Physiology

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In systems subjected to contaminants, some species persist while other species are lost. Toxicity testing and biological surveys have clearly demonstrated that species respond differently to contaminants. To increase our fundamental understanding of why and how species differ in their sensitivities however, comparative physiological approaches are needed. Biological surveys and bioassessments are generally successful in performing their primary objective, the detection of impaired assemblages. However, determining the causes of biological impairment in many streams remains elusive, particularly when several stressors resulting from different land uses within a watershed could potentially impair water quality. The correlative nature of the data they provide precludes the determination of cause-effect relationships. Similarly, the limitations of extrapolating traditional laboratory toxicity bioassays (often with surrogate species) to the field are well documented.

Recently, physiological attributes have been used to understand contaminant bioaccumulation. Physiological approaches make it possible to understand why species living in the same environment bioaccumulate contaminants to different degrees and, in some cases, why species are differentially sensitive to a particular contaminant. Using trace metal contaminants as an example, the Biotic Ligand Model (BLM) combines water