

2.3 Reflections of factors affecting size-at-age and strong year classes of herring in the North Pacific

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One approach to the investigation of linkages between oceanographic process and subsequent impacts on marine fish populations, is retrospective analyses of age-specific growth rates (size-at-age) from archive collections of scales or otoliths. This approach can be linked to independent observations on (1) temporal variation in abundance, (2) synchrony or asynchrony of year-class strength among different populations, or different species, and (3) habitat requirements of life history stages (eggs, larvae, juveniles, adults) that have different spatial and trophic characteristics.

Widespread geographic synchrony sometimes occurs in Pacific herring (Hollowed and Wooster 1995, Hay *et al.* 2001). An exceptionally strong year-class occurred in 1977 over a broad and geographic range (Fig. 2.3.1). It was strong in northern BC, parts of south-eastern and central Alaska and the Bering Sea (Hollowed and Wooster 1995). This 1977 year-class developed in different populations with different spawning times, with a range of about 3 months from the earliest to the latest mean spawning time. Pacific herring spawn in shallow, inshore inter- and subtidal waters. In many areas of the Pacific coast of North America, spawn deposition is monitored and quantified annually. Spawn deposition was not exceptional in 1977. Therefore, it follows that in 1977, survival from eggs to the juvenile and recruit stage, between 1977 and 1980, was relatively higher (or mortality was lower) than most other years. It also follows that the factor(s) that promoted the strong year-class were widely distributed in space and time.

Retrospective analysis of archived herring scales (Fig. 2.3.2) from northern BC populations, indicates that individuals of the 1977 year-class were of normal size, or slightly larger than normal, relative to samples from other years (Fig. 2.3.3).

After age 4, the relative size-at-age of individuals in the 1977 year-class declined, and was smaller than normal, which indicates that growth rate declined in older individuals. This retrospective analysis of growth from scale analysis was corroborated by analyses of catch-sampling data, collected routinely for the last 70 years. The size-at-age of 3-year-old members of the 1977 year-class was normal in most areas in 1980, but size-at-age of older individuals (*e.g.* age 6 fish collected in 1983) was smaller than normal (Fig. 2.3.4).

A strong 1977 year-class also occurred in several other species, including blackcod and lingcod (Hollowed and Wooster 1995). Climate-related changes, but not necessarily increases in abundance, also occurred in other marine species including salmonids (Beamish *et al.* 1999) and pollock *Theragra chalcogrammus* (Ohtani and Azumaya 1995). Further, there are periods when there has been synchrony of strong year-classes among different species in the North Pacific (Hollowed *et al.* 1987), which is evidence of environmental influence on the production of year-class strength.

The habitats occupied by age 1 and 2 herring are mainly inshore (Haegle 1997), whereas most of the older age groups (age 3 and older) tend to occupy shelf waters. During intensive summer feeding periods, juvenile herring are found mainly in shallow, nearshore waters of less than 50 m. In general, age 1 juveniles occur in shallower waters, closer to shore, than age 2 herring. In general, herring form shoals of similar-sized individuals so the two larger age groups do not mix, although both age groups of juveniles occur in the same vicinities, herring juveniles are widely dispersed through all BC coastal waters.

Over the last 70 years in British Columbia (BC), herring stomachs have been examined by different

people, in different years, at different places and at different herring life history stages. Wailes (1936) summarized the food of young herring mainly in the first summer of life. At very young stages, eggs (ova) and nauplii from various invertebrates are most important. Copepod nauplii seem to dominate the food but food composition varied with location. The youngest juveniles (age 1) fed mainly on copepods. Older, larger juveniles took various zooplankton, with euphausiids being common. More recent work examined gut data from herring juveniles in Georgia Strait, BC, Hecate Strait and Prince William Sound Alaska (Haegele 1997, Foy and Norcross 1999, Hay and McCarter 2001). In general the main food for herring at ages 1 and 2 is copepods. Therefore if the abundant 1977 year-class ate mainly copepods at ages 1 and 2, then copepods must have been abundant in nearshore northern waters, both in 1977 and 1978. From our present understanding of herring life history, there is little opportunity for trophic interaction (*i.e.* direct density-dependent competition for food) between age-classes: either among juveniles (ages 1 versus age 2) or between juveniles versus adults (age 3+ and older). In BC waters, probably the first opportunity for direct interaction occurs during the third winter of life, at age 2+, when (BC) herring start to mature sexually and join the adult stock. At this time, however, winter feeding is minimal and growth is slight.

The observations above can be summarized as follows. In 1977, and some other years, we see that strong year-classes can develop over broad areas of time and space. They develop in years when spawn deposition is normal, and sometimes even lower than normal. Further, sometimes they can be synchronous over broad areas of time and space. Synchrony may develop in other species. Retrospective analysis of herring scales indicates superior juvenile growth among strong cohorts, but decreased growth during older adult stages (in 1977). Strong year-classes can arise in years of normal or modest spawn deposition. These observations indicate that survival, between the egg and recruit stages, is enhanced. Such enhanced survival must occur during the juvenile stages that consume mainly copepods in nearshore habitats. Therefore strong year-classes may develop as a consequence of changes in these habitats.

If lower mortality of early life history stages is part of the explanation for the formation of the 1977 year-class - or other year classes, why did this happen? Presumably it must reflect decreases in mortality by starvation, disease or predation? In 1977, starvation seems unlikely, because juvenile growth was enhanced compared to other years. We have no evidence to suggest that disease routinely limits survival. Rather, outbreaks seem episodic, and this could explain years with exceptionally bad year-classes, but not the reverse. A decrease in predation, between the egg/larval stages and pre-recruit stage could occur if there were (i) fewer predators, or (ii) if the predators 'switched' or decreased predation on herring for a different prey species. Were predation rates on juvenile herring lower in 1977 and 1978? We have no data on this, but we observe that some common herring predators (lingcod and blackcod and some piscivorous salmon) also had strong 1977 year-classes. Therefore it seems improbable that there was a decrease in the potential community of herring predators between 1977 and 1980.

From the observations and reasoning above, we conclude that the most parsimonious explanation for the development of the strong 1977 year-class was a general decrease in predation of juveniles because the main herring predators had alternate prey. Such a reduction in predation could occur through predator switching during early life history stages - specifically, predators of herring chose to feed on an alternate food source. If this alternate food source was an unusually abundant supply of copepods, available both to the juveniles of herring and their predators, this could explain our observations. Specifically if predators preferentially switched to copepods, instead of herring juveniles, the consequence of a substantial increase in copepod availability would be both enhance survival and growth of juvenile herring.

If the cause(s) of the strong 1977 year-class was similar in all geographic areas where it occurred, from northern BC to the Bering Sea, and if the cause was from decreased predation associated with availability of an alternate food source, then clearly the factors which promoted this alternate food source were widespread. There have been

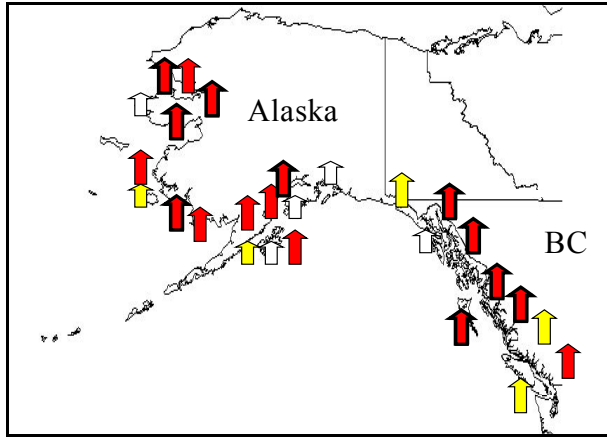


Fig. 2.3.1 Approximate locations of the strong 1977 year-class, indicated by arrows. Red arrows with dark outlines show locations where the 1977 year-class made up 70% or more of the spawning population as age 3 in 1980, or age 4 in 1981. Plain red and yellow arrows show populations where the 1977 year-class represented over 50% and 40% of the populations, respectively.

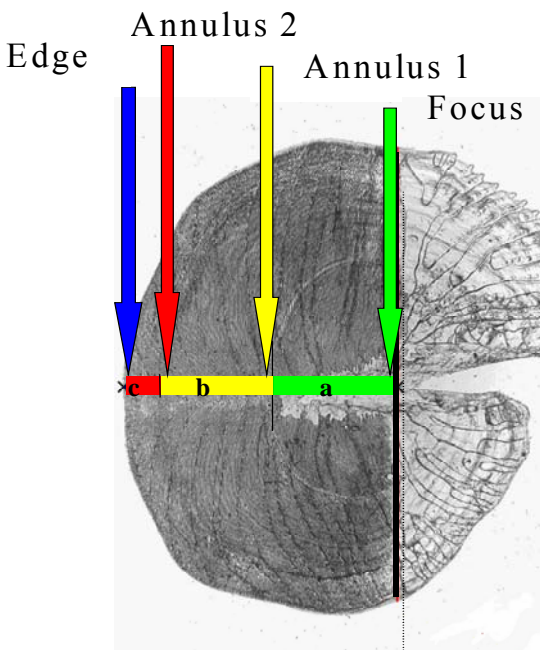


Fig. 2.3.2 A herring scale, showing the focus (start of growth) and the first and second annuli. Retrospective indices of age-specific growth rates during the first year (green bar a) and second year (yellow bar b) were determined by direct measurement of scales.

some suggestions (Hollowed and Wooster 1992; Polovina *et al.* 1995) that there can be such linkages between offshore oceanographic changes and changes in productivity or food abundance on shelf and inshore waters, resulting from mid-gyre changes, but these are not well understood. If there were such a relationship, the impact of an

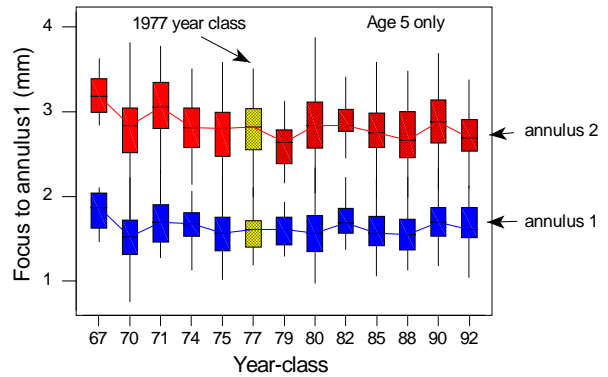


Fig. 2.3.3 Retrospective analyses of scale growth of 5-year-old-herring from archived collections of scales from northern BC. Scale growth, corresponding to juveniles at age 1 (blue rectangles) and age 2 (red rectangles), as estimated from comparison of focus: annuli distances, was normal in the 1977 year-class. The 1977 year-class is shown in yellow. The boxes and vertical lines represent the range and 95% confidence limits about the mean.

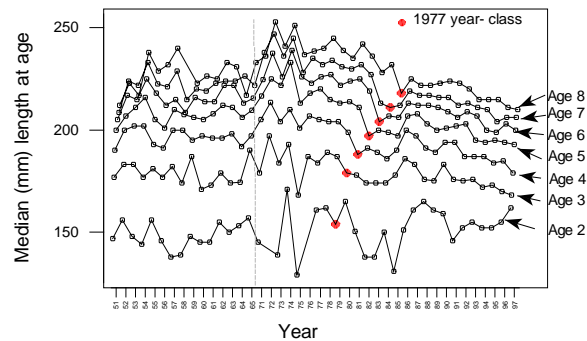


Fig. 2.3.4 Comparison of the size-at-age of the 1977 year-class with those of other years from catch sampling data collected in northern BC. The 1977 year-class (large dark circles) was normal (or slightly larger than normal at age 2). Thereafter, the relative size-at-age, relative to previous year-classes, decreased until age 8.

abundant production of zooplankton, specifically copepods, could explain both enhanced growth and year-class survival in herring and other species. There is a precedent for assuming that an abundant source of an alternate zooplankton prey species can reduce predation on herring. Ware and McFarlane (1995) showed that increased euphausiid production resulted in a decreased hake predation on adult herring off the west coast of

Vancouver Island. Similar mechanisms might operate at the juvenile stages, so factors promoting a strong year-class of herring might also support strong year-classes of other species, leading to synchrony between unrelated species such as blackcod and lingcod. Again, the answer is a tentative yes. Both of these species have early life stages (first several years of life) in nearshore waters.

2.4 Review for Pacific saury (*Cololabis saira*) study under the VENFISH project

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VENFISH (Comprehensive study of the Variation of the oceanic Environment and FISH populations in the northwestern Pacific) project was started in April 1997 and will end in March 2002. This project has been supported by Japan Agriculture Forest Fisheries Agency. The aim of this project is clarification of bottom-up control process for Pacific saury and walleye pollock in the Northwestern Pacific. More than 20 scientists from National Fisheries Research Centers at Hokkaido, Tohoku, Yokohama and Shimizu, and Hokkaido University and Tohoku University joined this project.

The VENFISH team is composed of 5 teams and there are primary production, zooplankton and fish teams. The fish team is composed of Pacific saury and walleye pollock groups. Between these three teams there is a plankton ecosystem model team and a fish population model team. In this report we will note our studies of saury, which is only one portion of this project.

The main target area of the VENFISH project is east of 160°E in the northwestern Pacific, and in that region there is a warm Kuroshio current and a cold Oyashio current. Between these two western boundary currents, there is a mixed water region,

and in that area many eddies are detached from the Kuroshio and Oyashio and make very complicated environments. The saury spawning starts in the mixed water region in autumn, moves to the Kuroshio area in winter, and moves back to the mixed water region in spring (Fig. 2.4.1) (Odate 1977; Watanabe and Lo 1989; Watanabe *et al.* 1997). Juveniles are advected to the Kuroshio extension region, then grow and migrate to the Oyashio region through the mixed water region for feeding. After sufficient feeding they migrate back to the Kuroshio region for spawning. On the southward migration, they are fished in the Japanese coastal zone. We will briefly report the new findings for Pacific saury in the later sections.

Feeding habitat

The feeding habitat of Pacific saury (*Cololabis saira*) changes according to the life stage and the location. Larvae smaller than 15 mm mainly feeds on *Oncea* and *Oitona* sp. (Nakata and Koyama 2002), whereas larvae and juvenile larger than 15 mm prefer *Calanus* sp. Young saury which migrate to the mixed water region mainly feed on *Euphausia pacifica*. In the Oyashio region they feed mainly on *Euphausia pacifica* and *Neocalanus cristatus* and the ration becomes the