A box model for the role of spawning distribution and the resulting juvenile herring distribution on recruitment in Prince William Sound, Alaska

M. J. Madison[1], E. D. Brown[3], F. O'Brien[4], V. Patrick[2], & D. A. Kiefer[1,4]

[1] University of Southern California [2] Prince William Sound Fisheries Research and Applications Planning [3] Flying Fish Ltd [4] System Science Applications

Email correspondence: kiefer@college.usc.edu

Objectives

•The first objective of this poster is to present our analysis of the spatial and temporal patterns of juvenile herring in Prince William Sound, *Clupea pallasi*, obtained from aerial and field surveys conducted during the SEA Project (Sound Ecosystem Assessment).

• The second objective of this poster is to describe how these surveys have helped shape and test a model of herring population dynamics that we have been developing over the last 3 years.

Adult Spawning Grounds

The Pacific herring population in Prince William Sound declined several years after the *Exxon Valdez* oil spill of 1989 and has not recovered. A look at the spawning grounds below shows an interesting phenomenon in which spawning grounds have altered over time. In 1975 spawning grounds were restricted to the northern east near Valdez and Montague Island in the southwest. Because of a shift in the Pacific Decadal Oscillation in 1976, the population grew and spawning grounds expanded through much of PWS including the northern and southeastern regions. The spawning population reached its peak in 1988. The rapid population decline in the early 90s was accompanied by a spatial contraction in which the distribution of spawning grounds more closely resembles that of the 70s. In particular the spawning ground in the north are absent in both the 1970s and since 1992. The spawning distribution in 1996 is typical of current spatial distribution and more closely resembles the distribution found in 1975 than 1988.

Such changes in the size and distribution of spawning grounds will cause changes in the abundance of metamorphs that reach bays within the sound and thus likely cause changes in the size and distribution of juvenile nursery grounds.

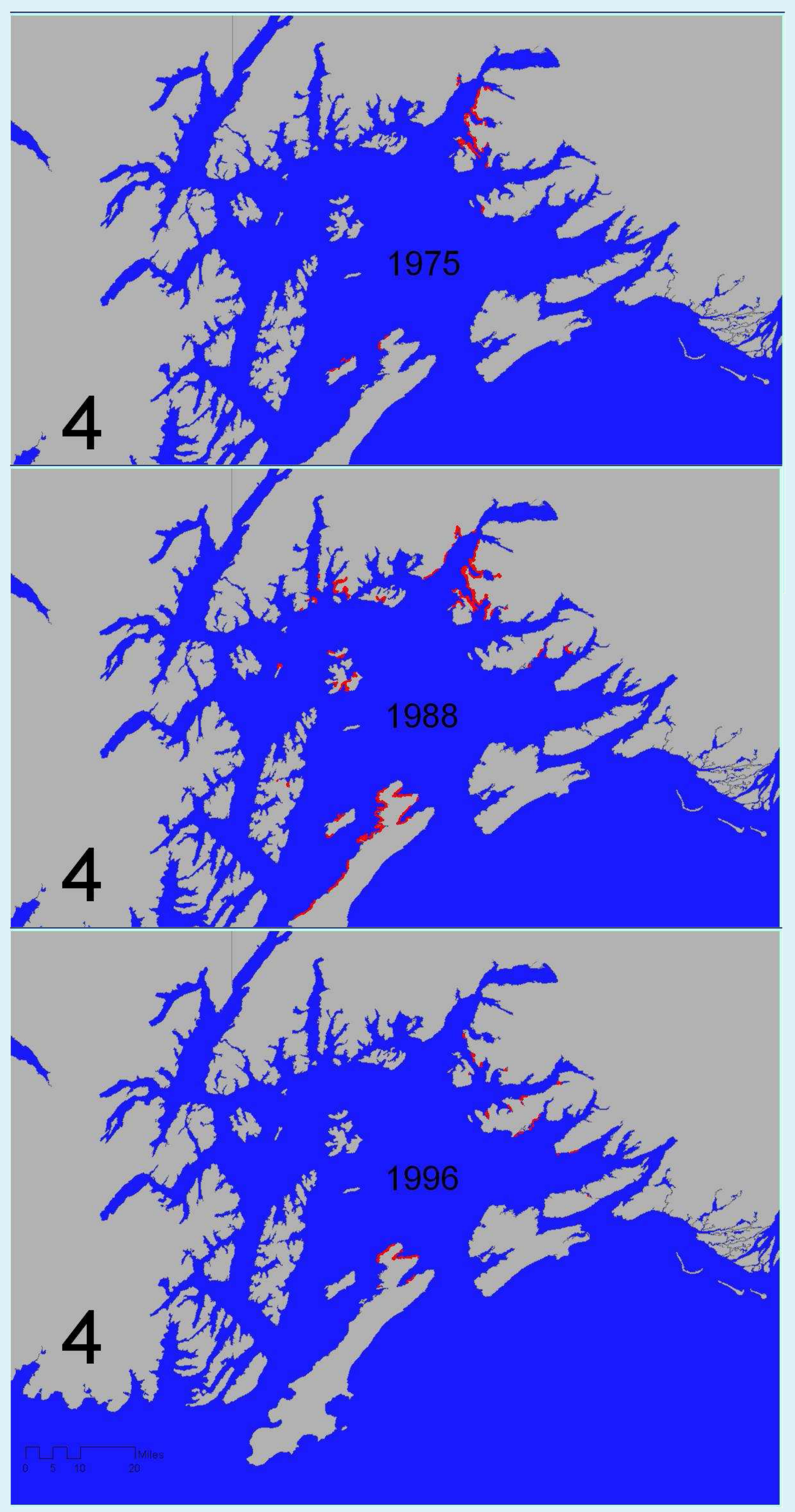

Fig 1: The spawning grounds of Pacific herring in Prince William sound in 1975, 1988, and 1996

Survey Descriptions

During the SEA Project Aerial and field surveys of the distribution of schools of age 0 through age 2 juveniles were conducted from 1995 to 1999. Shown below are two complete surveys of the bay conducted in June and July of 1996 and 1997. In these figures the size of each circle represents the number of schools at that location, while the colors index the age of the fish within each school with red, blue, and green indicating ages 0, 1, or 2, respectively. Because age 0 metamorphs do not enter their nursery grounds in the bays until July the schools found in the bays in June are mostly of age 1 and age 2 while in July the schools include all 3 year classes of juveniles. A comparison of Figure 2b and 2d for July 1996 and 1997 with 2a and 2c for July of 1997 shows that the schools of age 0 metamorphs are more broadly distributed than schools of 1 and 2 year olds. The large decrease in the spatial distribution of between age 0 metamorphs and age 1 juveniles indicates that either the age 0 metamorphs do not survive to age 1 in certain bays or that age 0 metamorphs move in certain bays move to other bays forming larger aggregates of age 1 survivors. We have not yet completed an analysis of which of these two options appears more likely and whether there exists a density dependence of these options. We also note that the spatial distribution of age 1 and age 2 individuals more closely resembles the distribution of adult spawning grounds than does the distribution of age 0 metamorphs. We have explored the possible consequences of density-dependent production of mature juveniles of spatially distinct nursery grounds in the metapopulation model describe in the next section.

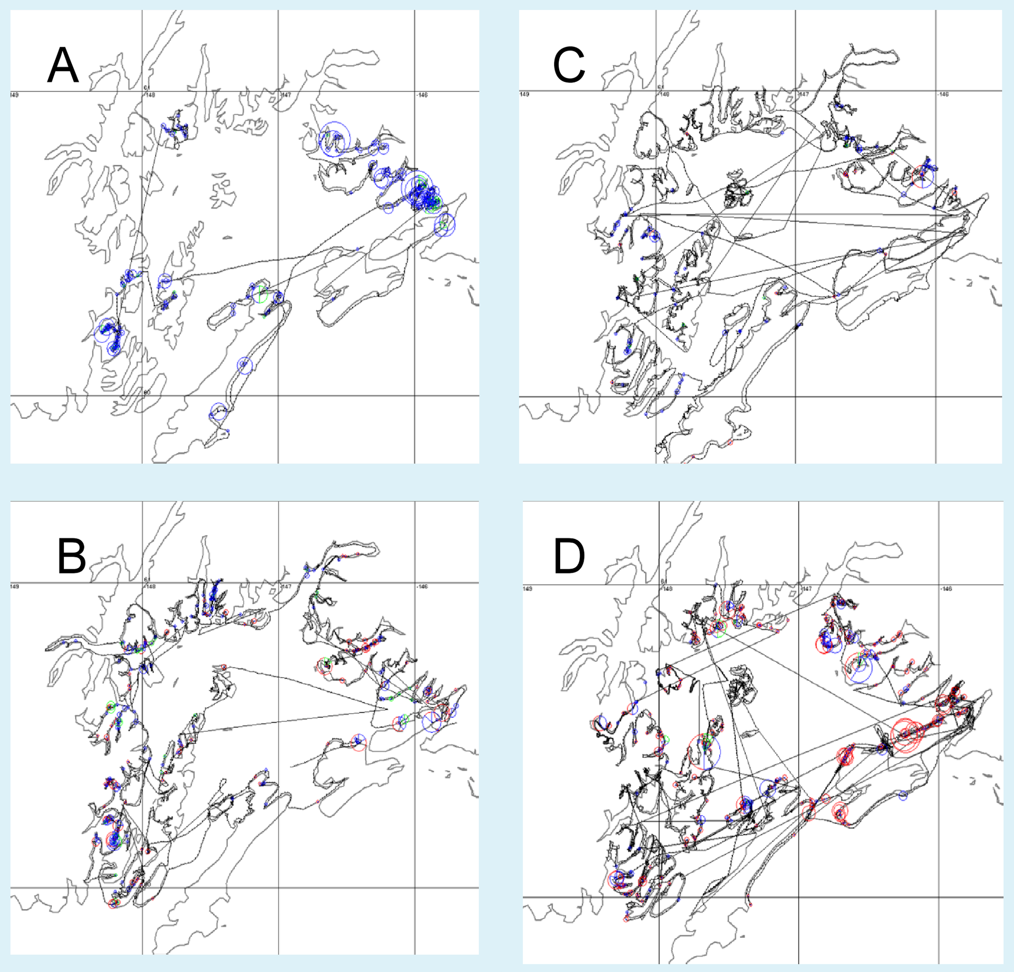

Fig 2 : Count of herring schools by age in four surveys of the bay. The images depict the following time periods: A : June 1996 ; B : July 1996; C : June 1997; D : July 1997.

Metapopulation Dynamics Model

We have developed a simple metapopulation model of PWS herring that consists of consisting of nursery grounds and spawning grounds that are coupled to each other to varying degrees by the transport of metamorphs from spawning grounds to different nursery grounds and the joining of mature juveniles from these different nursery to adult schools of different spawning grounds. The equations of the model are shown in figure 3 and the results of calculations are shown in figure 4. The results shown in figure 4 satisfy 4 conditions:

1. Adults spawning at ground 1 supplies metamorphs to nursery ground 1 only and vice versa. The supply of metamorphs to nursery ground 1 and 2 is the same linear function the population of spawning at each of their associated spawning grounds.
2. The annual production of mature juveniles for each nursery ground is the same sigmoid function of the abundance of metamorphs of that cohort that arrive at each nursery ground- the thresholds for metamorph seeding for minimal production and the maximum production are the same as is the value for maximal production.
3. Mature juveniles from nursery ground 1 and 2 fully mix and join adult schools spawning at a give ground in proportion to the relative abundance of adults that spawn at that ground. Adults always spawn where they first spawned as a new recruit.
4. The annual survival probability of adults is constant and independent of age and where the adult spawns.

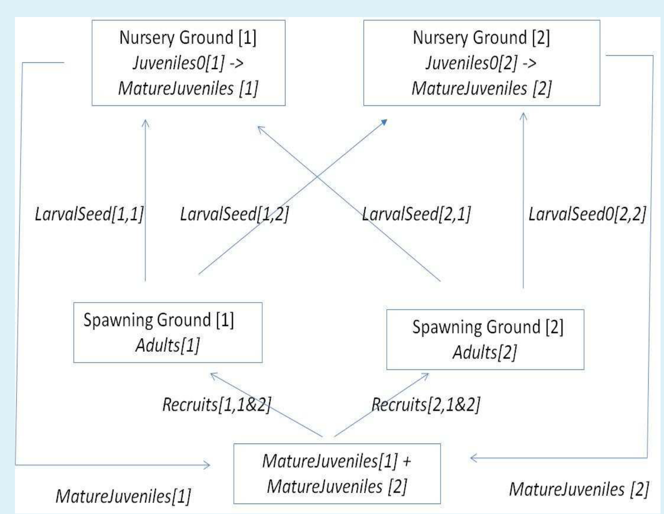

Fig 3 : Box model for functional spawning grounds for two potential nurseries.

Results of Calculations and Conclusions

In figure 4, we have solved our system of differential equations for changes the total abundance of adult herring (the sum of the two spawning populations) with changes in time for differing abundance of adults at the two spawning grounds. The steady state condition is indicated by the zero contour. This characterized by 3 states:

I. Two low density, stable states when either nursery ground 1 or nursery ground 2 is fully productive and the other is unproductive- indicated by the two short black arrows.
II. One high density, stable state when both nursery grounds are fully productive- indicated by the long black arrow.
III. Two unstable states in which the population tends to move towards either the low density or high density states- indicated by the two red arrows

In conclusion we propose that condition 2 of our model is partially supported by the aerial and field surveys of 1996 and 1997. We also propose that PWS herring were driven into a low density state in which the northern nursery ground was lost because of the high mortality rates of juveniles and adults that occurred between 1989 and 1993. Recovery to a high density state will require a uniquely successful recruitment such as that of 1976 in which the spatial distribution of nursery grounds will expand.

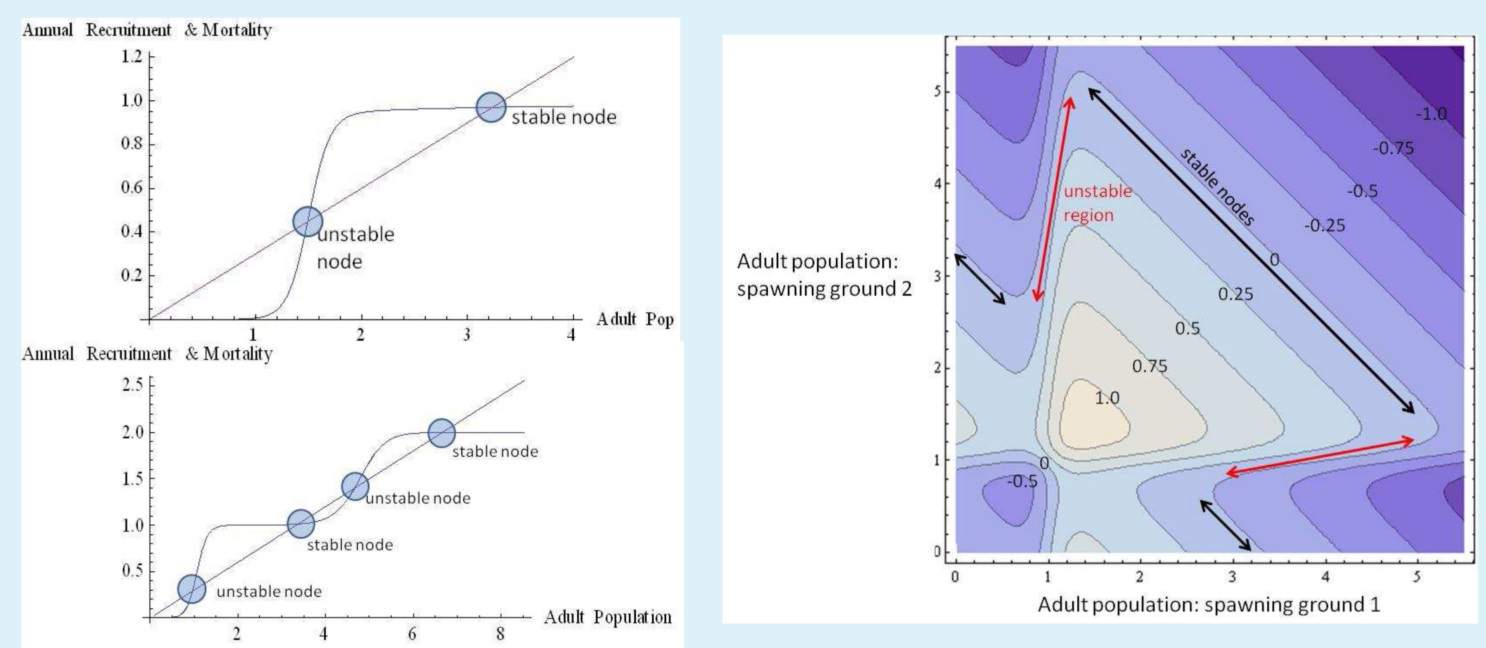

Fig 4: Plot of the annual recruitment and mortality as a function of the size of the adult population for a single nursery system and a double nursery system. Nodes are labeled based on the stability of the population. The third plot shows the areas of stability as we compare two adult spawning populations.

References

1. Brown, Evelyn Dale. "Stock Structure and Environmental Effects on Year Class Formation and Population Trends of Pacific Herring, *Clupea pallasi*, in Prince William Sound, Alaska." University of Alaska Fairbanks. September 2003.