Ichthyoplankton Information System: Taxonomy, Distribution, and Abundance of Early Life History Stages of Marine Fishes in the Northeast Pacific Ocean and Bering Sea

By
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The Recruitment Processes Program at NOAA's Alaska Fisheries Science Center (AFSC) has been studying the early-life-history (ELH) stages of fish (eggs, larvae, and early juveniles) since 1965. Our studies, conducted off the U.S. West Coast, in the Gulf of Alaska, the eastern Bering Sea, and within some of the most diverse and commercially valuable ecosystems in the world, depend on the collection and identification of samples of fish eggs and larvae (ichthyoplankton). These tiny creatures, most of which are less than an inch in length, help us answer important questions about the status of our ecosystem. Information about AFSC ichthyoplankton samples comprises a comprehensive dataset of locality, distribution, and abundance information for ichthyoplankton in the Northeast Pacific and Bering Sea in addition to an invaluable collection of specimens.

The importance of ELH studies has increased dramatically at the AFSC. Early-life-history research is routinely used to learn about recruitment mechanisms, to conduct population studies, and to monitor and manage our fishery resources through an ecosystem approach. Early-life-history studies are an invaluable aid to distinguish species and study the taxonomy and phylogeny of fishes. The ELH stages of many species remain unknown in the Northeast Pacific and Bering Sea, which limits their use in our studies as well as their application in studies to understand climate variability and change.

Two books authored by members of the Recruitment Processes Program address the most basic questions concerning our ichthyoplankton samples: what species occur in our study area, where and when are they found, and how abundant are they? *Laboratory Guide to the Early Life History Stages of Northeast Pacific Fishes* is a taxonomic guide to the identification of the eggs and larvae of more than 200 species of fishes found in our area (Matarese et al., 1989) and consolidates all known information on life history, meristics, and egg and larval development of fishes in the Northeast Pacific Ocean and Bering Sea. The labguide includes over 200 original illustrations to assist in the identification of pelagic fish eggs and larvae. More recently, a regional atlas that presents data on spatial and temporal trends in the dominant pelagic fish eggs and larvae (Matarese et al., 2003) was published as a companion to the labguide. The atlas summarizes and illustrates the distribution and abundance patterns of fish eggs and larvae of 102 taxa within 34 families found in the Northeast Pacific Ocean including the Bering Sea, Gulf of Alaska, and U. S. West Coast ecosystems. Data from the years 1972 and 1977-96 were used in the atlas to produce larval distribution and abundance maps. Below the larval map for each taxon, identifiable pelagic eggs are displayed on smaller presence/absence maps, as are adults in the study area, which were based on recent literature and data from AFSC groundfish surveys.

In the 16 years since the labguide was published, the task of identifying ELH stages has been aided by new technologies such as digital photography and radiography, genetics, and data-sharing via the Internet. Publication of the larval fish identification guide for the California Current (Moser, 1996) plus other new species descriptions have advanced our knowledge considerably for species in our region and provide additional illustrations of developmental stages for species whose identifications were already known. Because the Recruitment Processes Program has continued to support an active field program, more distributional data have become

[1] Additional information contributed by Jeff Napp and Janet Duffy-Anderson.

available beyond the 1972-96 time frame presented in the program's atlas. In addition, information on ichthyoplankton cruises (dates, gear used, areas sampled) has become available via the AFSC Ichthyoplankton Cruise Database web site (http://access.afsc.noaa.gov/icc/openframe.cfm) (Rugen, 2006). With all of this new information, there was a need to update existing data from the labguide and atlas and incorporate new data sources in a more efficient medium for distributing this information.

The consolidation of data updated from the labguide, atlas, and associated metadata as well as data from other sources both within and outside of the AFSC form the backbone of the Ichthyoplankton Information System (IIS) (http://access.afsc.noaa.gov/ichthyo/index.cfm)(Fig. 1). The IIS is an online, interactive, searchable information system that is updated routinely. The IIS consolidates ichthyoplankton ELH data from 1972 to 2003, representing almost 300 taxa in a single web site, and provides up-to-date information on the ELH of fishes in the Northeast Pacific Ocean and Bering Sea. The IIS serves as a versatile tool for a broad user base including scientists in taxonomic and systematic research, ecologists in larval fish identification, federal resource managers in preparing biological opinions, federal scientists in determining essential and critical habitats, environmental consultants, students, educators, and more.

Background and Historical Review

The Recruitment Processes Program has been collecting and analyzing ichthyoplankton for more than 40 years. Beginning in 1965, an ichthyoplankton program off the coasts of Washington, Oregon, and California was begun to determine the northernmost extent of Pacific hake (*Merluccius productus)* spawning. Only data on Pacific hake were kept and analyzed. Since that time, the scientific programs and studies under which Recruitment Processes has operated have determined where collections were made and the level of processing for the samples. For example, the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) began in 1971, sampling in the eastern Bering Sea, off Kodiak Island, Alaska, and off Vancouver Island, British Columbia; larval taxonomists collecting the samples also identified all larvae and eggs. In 1980, the Plankton Sorting and Identification Laboratory in Szczecin, Poland, began processing the increasing numbers of ichthyoplankton samples collected by the AFSC. For most of the early 1980s, sampling was conducted along the Washington, Oregon, and northern California coasts in cooperation with the Soviet Union. The Fisheries Oceanography Coordinated Investigations (FOCI) Program began in 1985 and initially focused on physical and biological factors affecting survival of ELH stages of walleye pollock (*Theragra chalcogramma*) in the Gulf of Alaska. The Northeast Pacific Global Ocean Ecosystems Dynamics Program (GLOBEC) was added to the Recruitment Processes Program in 1998. The GLOBEC research includes studies comparing multispecies ichthyoplankton assemblages from the Gulf of Alaska, Bering Sea, and U.S. West Coast and larval flatfish transport studies, concentrating on the influence of El Niño in the Gulf of Alaska. More detailed information on historical background of the program is available in the history section of IIS web site.

Ongoing Investigations Online

The intent of the IIS is to present ongoing research within the Recruitment Processes Program and to disseminate associated ichthyoplankton metadata that are generated from new research initiatives. As research questions direct cruises into new geographic areas or during seasons that have been infrequently sampled, timely updates are made with the IIS to make the data accessible to everyone.

Over the years the Recruitment Processes Program has broadened its focus from single species studies to a more holistic ecosystem approach. To reflect this broadening of its investigations, the program recently agreed to put all existing and future projects under the newly formed EcoFOCI umbrella (Ecosystem & Fishery-Oceanography Coordinated Investigations), which consists of the new North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) project and the former FOCI project. EcoFOCI continues to study relationships between the marine environment and the survival of commercially important fishes. For the Gulf of Alaska, EcoFOCI conducts process studies and annual larval surveys and incorporates these data into recruitment predictions for walleye pollock. Correlation modeling methods have been developed to analyze hydroacoustic survey results of spawning aggregations, ichthyoplankton surveys of larvae, estimates of spawning biomass and recruitment from annual stock assessments, measurements

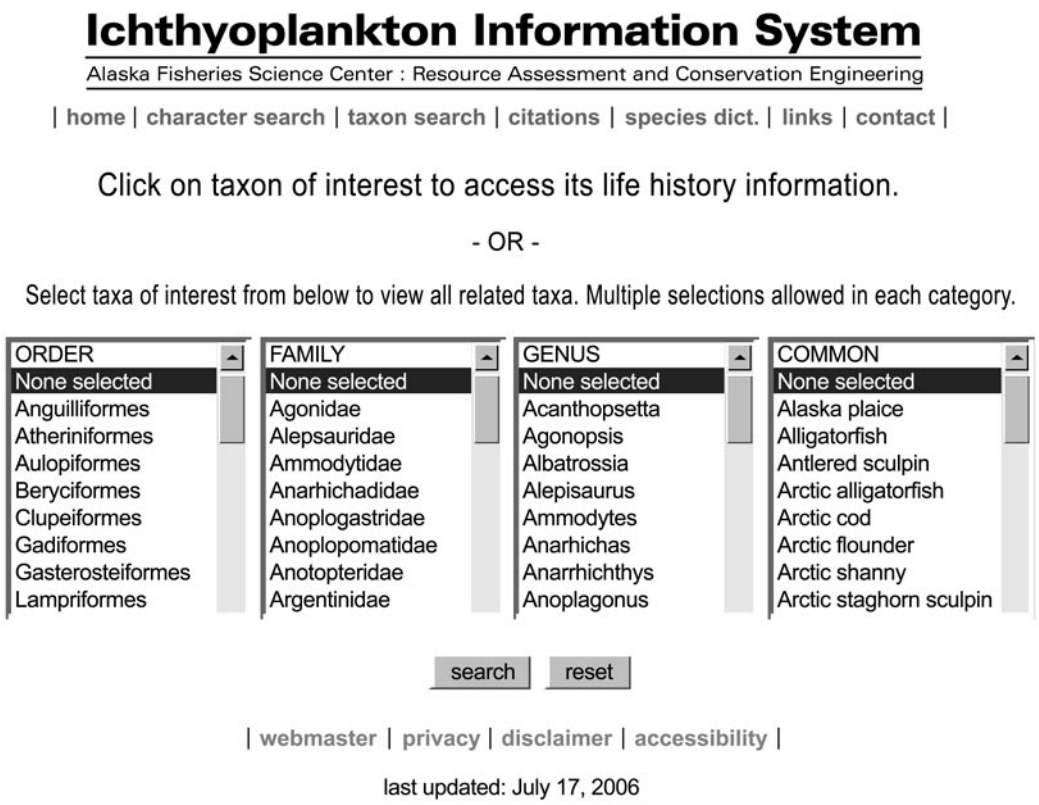

Figure 1. An example of the Recruitment Processes Program's Ichthyoplankton System's (IIS) web interface, showing the IIS taxon search page.

of ocean temperature, winds, rainfall, sea-level pressure gradient, and other biological and physical factors. Ongoing work also seeks to evaluate the geographic and seasonal factors affecting productivity of forage fishes (age-0 walleye pollock, capelin (*Mallotus villosus*), and eulachon (*Thaleichthys pacificus*)) in the western Gulf of Alaska. EcoFOCI studies in the Bering Sea continue to document the role of walleye pollock in the eastern Bering Sea, including their interaction with seabirds and marine mammals.

GLOBEC-supported investigations in EcoFOCI have identified dominant taxa and multispecies assemblages in the ichthyoplankton, described their horizontal distribution patterns, and related these patterns to the oceanographic variables. Temporal variation in the composition, distribution, and abundance of these assemblages is being investigated further. In addition, we are examining temporal variability in the occurrence, abundance, and distribution of many ichthyoplankton species that are numerically dominant, such as flathead sole (*Hippoglossoides elassodon*) and arrowtooth flounder (*Atheresthes stomias*), or ecologically important, such as capelin.

The North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) project within EcoFOCI seeks to observe and understand how climate determines the structure and function of the Bering Sea and Gulf of Alaska ecosystems. Goals of this work include incorporating climate and climate-forced environmental variables into single species and ecosystem assessment models, and supplying critical ELH information for formulating climate-forced models to help predict annual variations in fisheries recruitment. The NPCREP work to date includes identifying how ichthyoplankton assemblages are forced by mesoscale meteorological and oceanographic conditions (e.g., El Niño) in the Bering Sea and how fall ichthyoplankton assemblages may be influenced by climate-induced variations in local hydrography in the Gulf of Alaska. Other NPCREP studies are investigating the effects of climate-forced variations in hydrography on advective processes associated with onshore transport of ichthyoplankton, developing cross-shelf exchange tracers composed of offshore ichthyoplankton assemblages, and identifying key species that may be indicators of changes in oceanographic conditions or cross-shelf flow. Finally, work also includes efforts to evaluate the copepod community in relation to environmental conditions in the Bering Sea and Gulf of Alaska.

The most recent recruitment studies within EcoFOCI center on continuing ichthyoplankton

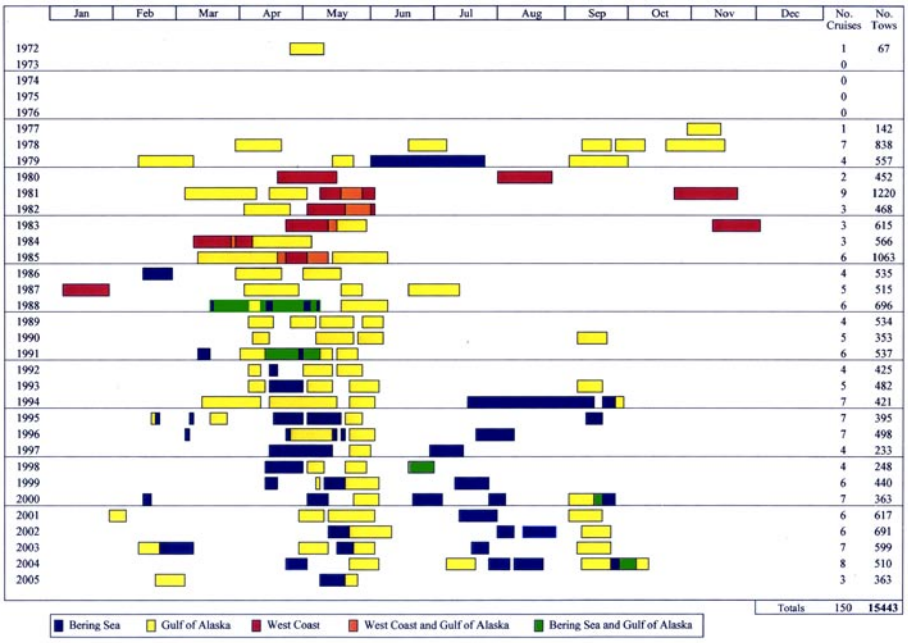

Figure 2. Geographic and temporal coverage of Recruitment Processes Program ichthyoplankton survey data 1972-2005 available in the larval fish database (ICHBASE).

surveys and analyzing data from historical time series. In particular, emphasis is on investigations of interannual trends among dominant taxa, especially in the Gulf of Alaska. It is increasingly important to look at longer time scales, such as regime shifts and climate change, as we continue to plan new studies in the Northeast Pacific. This will require research that is long-term, community-focused, and includes multiple trophic levels. Fluctuations in forage fish population abundance and community structure can have consequences on the health and survival of top predator species (e.g., salmon, seabirds, and marine mammals such as Steller sea lions) through changes in the amount, distribution, and variety or quality of food available to them. Such studies are under way to investigate interannual trends in the distribution and abundance of larval forage species as well as in zooplankton communities. All ichthyoplankton data derived from the EcoFOCI studies are incorporated into the IIS as they become available.

Geographic and Temporal Coverage Online

Most data for the initial Pacific hake and MARMAP studies in the mid-1960s and early 1970s were not entered into a permanent database. Our database (now called ICHBASE) became more consistent in 1977 with the Outer Continental Shelf Environment Assessment Program (OCSEAP), the first broad-scale program offering scientists the opportunity to study seasonal occurrences of eggs and larvae in the Northeast Pacific Ocean (Fig. 2). During the 1970s, sampling intensity was highest in the Gulf of Alaska east of Kodiak Island. The OCSEAP Program offered broad monthly coverage (February-November), but, overall, only 16 cruises were conducted between 1972 and 1979 (no cruises from 1973 to 1976).

By the mid-1980s, the number of surveys increased dramatically due to the addition of U.S. West Coast cruises (U.S.S.R./U.S.A. 1980-1987) and the initiation of the FOCI Program. Sampling was greatest in the Gulf of Alaska in Shelikof Strait and southwest of Kodiak Island. January was included in the monthly coverage, but most cruises occurred from March to May, which is the peak period of walleye pollock spawning in Shelikof Strait. Only four cruises were conducted in the Bering Sea, but coverage was expanded with nine cruises conducted along the U.S. West Coast.

Coverage in the 1990s was expanded to include more sampling in the Bering Sea with the onset of the Bering Sea FOCI and Southeast Bering Sea Carrying Capacity (SEBSCC) programs. More

cruises were conducted than in the 1980s with more Bering Sea cruises than ever before. Summer coverage was also more extensive. From 2000 to 2005, slightly more than half of our cruises were in the Gulf of Alaska. Coverage has been expanded into late January - early February in the Gulf along with consistent sampling in late summer. Cruise plans for 2006 and beyond shift a greater number of surveys and directed studies to the Bering Sea. Ichthyoplankton data related to specific research are generally published by region (e.g., northeastern Pacific, Bering Sea or West Coast) or by a specific time period (e.g., spring, summer, fall, or for certain years). Data available through the IIS covers all regions studied over most years encompassed with our database.

Information and Data Sources

The taxonomic data in the atlas and IIS were obtained from eggs and larvae collected during ichthyoplankton surveys conducted by the Recruitment Processes Program. Data on distribution and abundance of eggs and larvae used to create maps were based on surveys from 1972 and 1977-96. Collection data for cruises can be found online in the AFSC Ichthyoplankton Cruise Database. The majority of the data are from samples collected using a MARMAP type bongo sampler with an inside diameter of 60 cm and a 0.333 or 0.505-mm mesh net. Data from 1-m Tucker trawls were used only for cruises in which Tucker trawls were the primary gear (9 cruises, 717 tows).

A Sameoto neuston sampler, with a mouth opening 0.3 m high x 0.5 m wide and a 0.505-mm mesh net, was used sporadically throughout the time series to collect eggs and larvae that reside in the upper surface waters. Data from the neuston tows were selected to generate maps and graphs for nine taxa for which the best geographic distribution pattern was described using surface gear.

The number of individuals caught in each of the three sampling gears (i.e., bongo net, neuston net, and Tucker trawl) was standardized to number caught per 10 m^2 of surface area. Catches from bongo and Tucker gear were standardized based on net mouth area and tow depth and length. Samples collected by neuston gear were standardized to number caught per 10 m^2 of surface area based on net mouth width and tow length. In comparing neuston catches and bongo catches per unit area, the neuston catches are much smaller because the volume of water filtered is much smaller. Identifications are verified by the taxonomic team at AFSC using information found in the labguide and supplemented by a number of more recent publications.

The increase in our taxonomic knowledge over 40 years has allowed our basic understanding of the early life history of species to be expanded and fine-tuned. Of the 646 known fish species that occur in the Northeast Pacific Ocean, we can currently identify a portion of the ELH stages for about 320. Complete coverage of 289 taxa is presented in the current version of the IIS.

Most of the larval data included in the atlas and IIS can be found in our labguide or CalCOFI Atlas 33. Any taxa that spawn in our study area and have been described with accompanying illustrations can be found within the IIS. All individual species covered in the atlas are found in the IIS; taxa covered only at the genus or family level are not included. Additional maps will be added to the IIS as distributional data are published.

Similar to the larvae as described above, most of the fish egg taxa included in the atlas and IIS can be found in our labguide or CalCOFI Atlas 33. Of larval taxa in the IIS, any of their respective eggs that have been described are also included. Many have accompanying illustrations.

Data were restricted to pelagic fish eggs due to sampling strategies and gear limitations. Distributional maps depicting presence/absence are presented in the atlas and IIS. As with larvae, additional egg distribution maps will be added to the IIS as data are published.

Format and Methods

For the initial concept and design of the IIS, a rockfish database developed by ichthyoplankton team members served as a model. The enormity of the project required additional help, which was provided through a contract with the University of Washington (UW). Over a period of 3 years, three UW students worked half-time entering and updating data and literature, scanning and incorporating illustrations into new layouts, defining and coding pigment, and researching publication permissions. Assistance with illustration organization, data verification, pigment coding, initial review, and initial beta testing was provided by other members of the Recruitment Processes Program. Maps from the

atlas were incorporated into the format and are described below (Fig. 3).

Maps

Larval Occurrence Map - Fish density data (catch per 10 m^2) were compiled from ICHBASE using ArcInfo (2001) software and converted into ArcInfo coverages (data layers). A chloropleth map design, which uses colors to create darker or lighter areas in proportion to the density of distribution, was chosen to depict distribution and abundance. All cells that were sampled, but contained no individuals of the taxon, are symbolized as gray, indicating absence. The remaining data were classified using quantiles: data were ranked, ordered, and divided into four categories, each containing an equal number of observations. The legend shows the range for each class, and the colors are hierarchical in that lighter colors connote lower levels of abundance and darker colors connote higher levels.

Adult Occurrence Map - The occurrences of adults were derived for the most part from unpublished AFSC data residing in RACEBASE, an Oracle database. These data form the backbone of the AFSC's Resource Assessment and Conservation Engineering (RACE) Division's Groundfish Assessment Program, which conducts annual resource assessment surveys and processes the data for RACEBASE. The geographic extent of RACEBASE data covers the continental shelf and slope of western North America and northeastern Asia from the Arctic Ocean (72°14'N, 167°52'W) south through the eastern half of the Chukchi Sea, throughout the Bering Sea (including the continental shelf of northeast Siberia), the Aleutian Basin and eastward along the Aleutian Islands, and along the U.S. West Coast from the Gulf of Alaska to the southern border of California (32°28'N, 119°18'W). Blue squares show where adults were found when sampled. Gray squares denote where samples were taken, but no individuals of that taxon were found. Cell sizes appear smaller than those in the average larval abundance map because of the change in map scale. Adult occurrence maps generated with alternative data are identified with an asterisk in the legend on individual taxon pages. Adult occurrence maps generated with alternative data other than RACEBASE show presence only because the geographic extent of individual surveys was unknown (no gray area appears on the map).

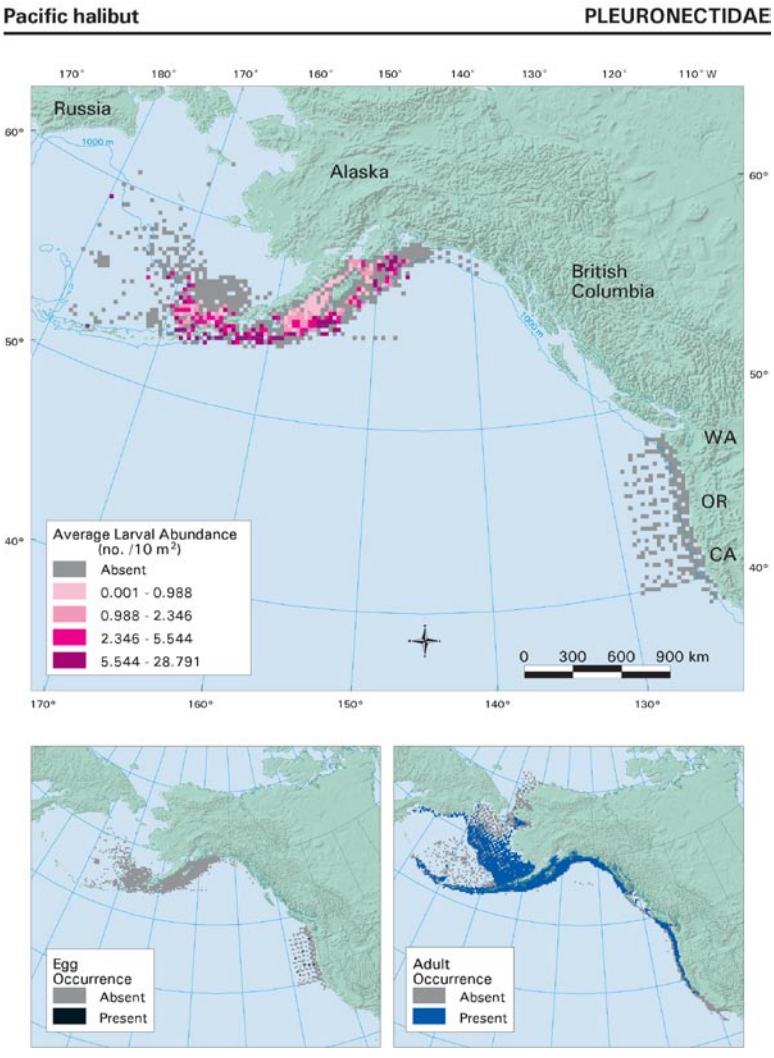

Figure 3. An example of an atlas map showing larval distribution and abundance (large map) and egg and adult distribution (lower maps), which are also found in the IIS.

Egg Occurrence Map - The data for the egg occurrence map was processed similarly to the adult occurrence map, showing presence or absence of eggs of the taxon. Gray squares denote where samples were taken, but no eggs were found. Black squares show the presence of the taxon.

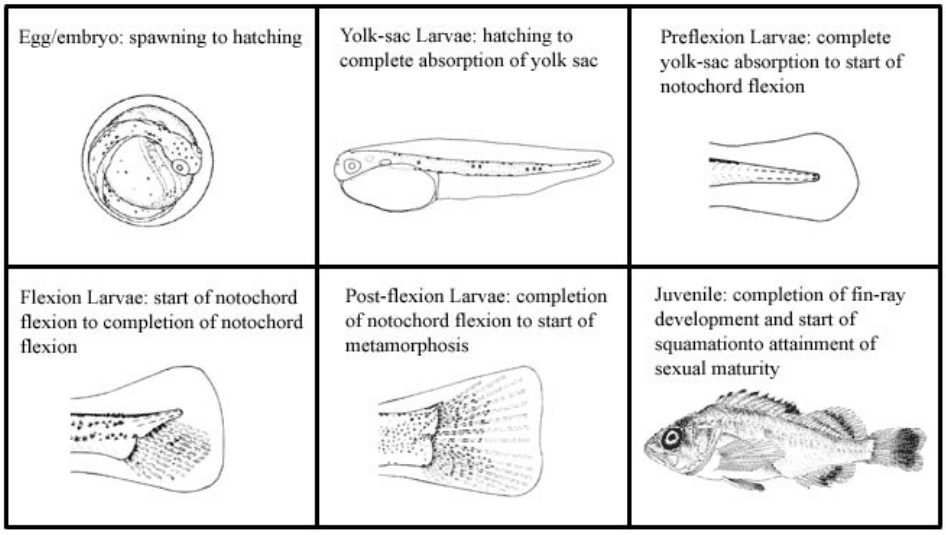

Figure 4. Early-life-history developmental stages of fish (egg/embryo, yolk-sac, preflexion, flexion, postflexion, and juvenile) used within the character search in the IIS.

Using the IIS

The organization of the IIS Web site allows the user to browse through 289 taxa currently included in the IIS or search the database by a number of fields, including meristic (countable structures such as vertebrae, fin spines and rays) and pigmentation characters, permitting those without access to collection material to attempt identification of unknown ELH specimens. For each taxon, there is a gateway webpage with tabs that direct the user to meristic data, life history and ecological data, ELH descriptions, illustrations, spatial and temporal distribution and abundance data, and relevant literature. The distribution data include maps and links to the original collection data, which can be downloaded to the user's personal computer. An additional benefit of the online format of the IIS is that it is linked directly with the UW Fish Collection where a majority of the specimens are deposited, thus allowing the user quick access to specimens of interest. Other available links from the IIS main page are described below: Character Search, Taxonomic Search, Citations, Species Dictionary, and Links.

CHARACTER SEARCH

This option is designed to use for an unidentified egg or larval fish specimen from the Northeast Pacific or Bering Sea. The first step is to determine the developmental stage of the specimen (Fig. 4). Although results will be more accurate if one of the six stages is specified, a character search can be used for a specimen of unknown life history stage and will produce the most matches to the search criteria, thereby increasing the chance that the unidentified fish larva will be included in the list of matches.

CHARACTER SEARCH CRITERIA

The IIS allows the user to search by meristic characters, pigment characters, or both.

Meristic – The user can search on any or all of eight meristic characters: vertebrae (total, precaudal, and caudal), branchiostegal rays, gill rakers (upper and lower), pelvic-fin spines and rays, dorsal-fin spines and rays, pectoral-fin rays, anal-fin spines and rays, and caudal-fin rays.

Pigment – Search is available on any combination of 16 defined pigment regions (Fig. 5).

TAXONOMIC SEARCH

The IIS allows the user to browse, alphabetically or phylogenetically, the list of species included in the system through a taxonomic search. Alternatively, the user can select taxa by order, family, genus, or common name using the drop down lists that appear when "taxon search" is chosen (Fig. 1). After selecting the desired taxon, the list of items matching the criteria appears on the left side of the page. Selecting "taxon search" prior to each action resets all taxa to "none selected"; selecting the back arrow browser menu bar leaves previous searches intact. The four hierarchies of taxa appear independently of

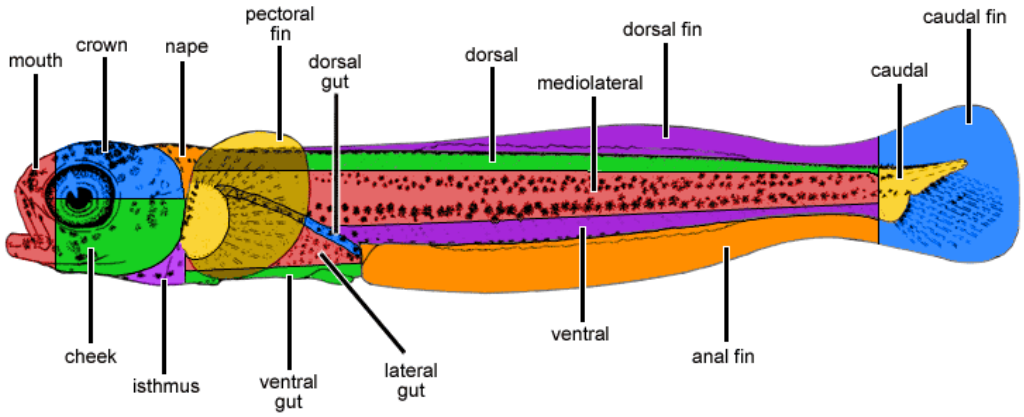

Figure 5. Pigmentation regions used within the character search in the IIS.

one another; e.g., names of species from an unrelated order, family, genus, and common name may be listed at the same time.

TAXON PAGE

For each taxon, the information is organized into six categories as listed on the species header: illustrations, meristics, life history, ELH description, distribution, and literature. There are also links that lead directly to further information and data for each taxon on other Web sites.

Illustrations - For each taxon, if available, illustrations of the following life history stages are presented: egg, yolk sac, preflexion, flexion, postflexion, and either a transforming or early juvenile (Fig. 6). Sources for these illustrations include those previously published and originals drawn from specimens in our collections; collection data are provided for original illustrations. The majority of illustrations are from the labguide, but new and revised figures have been added throughout to reflect the more recent taxonomic literature.

Meristics - For each taxon, if available, minimum, modal, and maximum counts are given for the following meristic characters: vertebrae (total, precaudal, and caudal), upper gill rakers, lower gill rakers, branchiostegal rays, caudal-fin rays (upper secondary, upper principal, lower principal and lower secondary), pelvic fin (spines and rays), pectoral-fin rays, dorsal fin (spines and rays) and anal fin (spines and rays). Unknown meristic counts are denoted with an 'X'.

Life History - For each taxon, if available, data for the following life history features are presented: General (geographic range, ecology, ELH pattern, and longevity) and Spawning (area, season, mode, fecundity, age at maturity, and migration). Sections are blank if data are unknown.

ELH Descriptions - For each taxon, a description of the eggs and larvae is provided along with pigment and/or morphological diagnostic characters for distinguishing them from similar-looking species. If available, data for the following ELH features are presented: Egg (diameter, number and size of oil globules, yolk, chorion, and pigment on yolk and embryo) and Larvae (hatch size, preanal length, flexion length, length at transformation, sequence of fin development, and larval pigmentation). Sections are blank if data are unknown.

Distribution - This page is the atlas map as described above and is composed of three maps for each taxon: a larval distribution and abundance map, an egg occurrence map, and an adult occurrence map. Larval distribution data used for the map can be downloaded with a single mouse click.

Footnotes - A list of literature referenced specifically for each taxon is provided. General references are listed first, followed by footnotes, and sources for figures. Choosing the "citations" tab on the gateway page also provides a complete list of references.

CITATIONS

The IIS includes a complete list of literature referenced for all 289 taxa found on the IIS Web site. The citations include references cited in the text, footnotes, and sources of figures.

SPECIES DICTIONARY AND LINKS

A complete list is available of all taxa included on the IIS Web site. Relevant links to other web sites serves as an additional resource.

Summary

The IIS is an ongoing project designed to provide the user with the most current data available in our program. For those preferring a hard copy of information on the Web site, output in the form of a dynamic pdf is under construction. The pdf will consist of a four-page layout for each taxon with a map (three-page if no map is available) consisting of the items in the species header as described above, and it will be available to users as sections (species or family, e.g., Scorpaenidae) or as an entire volume (about 1,000 pages). The IIS will be updated on a routine basis as we continue to add new taxa to the species list, update maps, and incorporate new information as it becomes available.

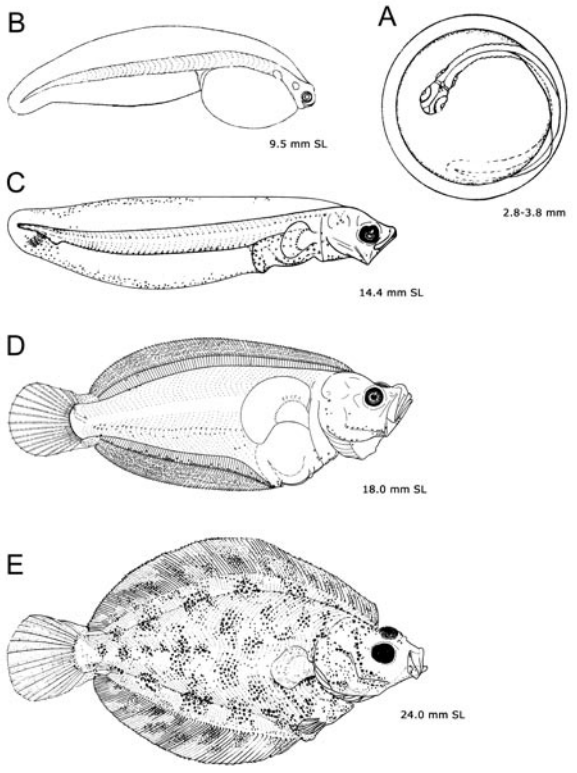

Figure 6. Larval development of Pacific halibut as presented on the illustrations page found for taxa in the IIS.

Additional Resources

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