Advancements in ichthyoplankton taxonomy in the large marine ecosystems of Alaska: 1979–2021

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Abstract—As fisheries management strategies in the United States become more holistic by including ecosystem data, there is a need to refine taxonomic expertise within large marine ecosystems (LMEs) to support ecosystem management and investigate climate-mediated processes. In this study, we provide an update on the taxonomic resolution of the early life history stages of fishes in the LMEs of Alaska, a highly productive but rapidly changing region, explore patterns of species richness by LME, and contribute new illustrations. The Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) program at the Alaska Fisheries Science Center (AFSC) collected ichthyoplankton samples for 3 LMEs during 1972–2021: the Gulf of Alaska (1972–2021), the southeastern Bering Sea (1979–2019), and the U.S. Arctic (2004–2019). Through these sampling efforts, we can now identify the eggs of 127 species and the larvae of 353 species, representing 26% and 71%, respectively, of the described species of Alaska. Species richness reached an asymptote in the Gulf of Alaska by the late 1980s but increased in the Bering Sea until 2013, whereas no pattern was present in the Arctic. Illustrations are contributed for 8 species, many of which are early juveniles, which is a potential recruitment bottleneck. The ability to identify individuals with high taxonomic resolution across life history transitions is critical for generating early life history indicators that support sustainable fisheries management.

Introduction

Fisheries management in the United States is shifting from a single-species or stock approach to becoming holistic and linked to ecosystem processes (Lynch et al., 2018). There is a need to understand not only what species are present in an ecosystem but also what biological and oceanographic factors favor reproduction, survival, and growth (Lynch et al., 2018) to meet this next-generation stock assessment goal. The Alaska Fisheries Science Center (AFSC) is increasingly linking ecosystem indicators with stock assessments to provide an environmental context when adjusting acceptable biological catch (Dorn and Zador, 2020; Ferriss and Zador, 2020; Ortiz and Zador, 2020; Siddon, 2020). Newly implemented risk tables require environmental and ecosystem considerations to document acceptable biological catch modifications (Dorn and Zador, 2020). Indicators based on the early life history stages are becoming increasingly important to management and are incorporated into another innovative stock assessment tool: the ecosystem and socioeconomic profile (Dorn et al., 2019; Hanselman et al., 2019; Shotwell et al., 2022). These applications to the management of Alaska's fisheries are possible only through taxonomic expertise and advancements of the ichthyoplankton laboratory of the Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) group at AFSC.

Hjort (1914, 1926) ushered in over a century of scientific advancement to understand recruitment variability and the role that the environment plays in mediating that variability (e.g., Cushing, 1975; Lasker, 1978; Iles and Sinclair, 1982; Cury and Roy, 1989). However, another consequence of Hjort's legacy relates to ichthyoplankton taxonomy and systematics: how can we attempt to understand recruitment variability in commercially exploited species if we cannot identify the early stages? Identifying early stages is challenging due to similar morphologies among taxa, requiring years of expertise and specialized training to achieve such high taxonomic resolution (Collette and Vecchione, 1995; Leis, 2015). Accurate identification of fish eggs and larvae at the species level can provide valuable insight into phylogenetic relationships and the evolutionary history of fishes (Ahlstrom and Moser, 1981), spawning and nursery habitat use (Logerwell et al., 2015; Porter and Ciannelli, 2018), transport and dispersal pathways (Goldstein et al., 2020), robust biodiversity estimates (Nielsen et al., 2021), and sources of recruitment variability in commercially exploited species (Houde, 2009), all of which contribute to effective ecological monitoring and fisheries management. Additionally, the larvae often look very different from the adults due to adaptations to overcome life at low Reynold's numbers, which means larvae perceive the environment as viscous relative to adults (Miller and Kendall, 2009; Leis, 2015; Yavno and Holzman, 2018). Therefore, fish larvae have adaptations that are absent in juveniles and adults, leading to stage-specific differences in essential fish habitat, which is another facet of fisheries management (Pirtle et al., 2019) that requires high taxonomic resolution to discern.

Alaska supports many productive fisheries, including walleye pollock (*Gadus chalcogrammus*), the world's most lucrative single-species fishery, and many other productive fisheries. These fisheries account for more than 60% of all fish caught in U.S. coastal fisheries and are valued at $4.5 billion (NMFS[1]; Bailey, 2021). We will focus on the large marine ecosystems (LMEs) of Alaska, which consist of the Gulf of Alaska, the southeastern Bering Sea, and the Chukchi and the Beaufort Seas (Arctic). The objectives of this study are as follows:

1. Provide an update on the current taxonomic resolution of the early life history stages of fishes in Alaska's LMEs.
2. Explore species richness patterns in each LME.
3. Contribute new illustrations and descriptions to the developmental series of several species with gaps in life history transitions.
4. Identify current gaps and future research directions related to ichthyoplankton taxonomy and systematics.

Materials and methods

Estimating taxonomic resolution

We need an accurate estimate of the number of valid species to calculate advancements in taxonomic resolution by decade for the marine fish taxa of Alaska. There are approximately 496 marine species in the LME of Alaska (Mecklenberg et al., 2002), with an additional 2 dozen recently described species and several valid but undescribed species (Orr[2]). However, 25 species lack descriptions of early life history stages (i.e., eggs, larvae, juveniles) in the marine realm (Mecklenberg et al., 2002) and are excluded from further consideration, leaving 495 species in marine systems with early-stage descriptions. The sampling program in EcoFOCI uses almost exclusively pelagic sampling gear (e.g., bongo nets), so the collection of early life stages is often limited to pelagic eggs, larvae, and juveniles and excludes stages and species that are found along the benthos, are associated with rocky or other habitat structure, or are nearshore (Matarese et al., 2003).

We calculated taxonomic resolution as the number of species with early life history descriptions divided by the total number of described species with pelagic early life history stages encountered within the LMEs of Alaska. These estimates were then compared to past estimates of taxonomic resolution by decade using Matarese et al. (1989), Busby et al. (2000), Matarese et al. (2003), and Matarese et al. (2011).

Ichthyoplankton time series

We examined the ichthyoplankton records from 3 LMEs: the Gulf of Alaska (1972–2021), the southeastern Bering Sea (1979–2019), and the Arctic (Chukchi and Beaufort Seas; 2004–2019). Records for eggs and larvae collected with a 60-cm diameter bongo and a 1-m^2 Tucker trawl, equipped with 505-µm or 333-µm mesh nets, from each LME were used as they are the most consistently sampled gear types by EcoFOCI. Bongo and Tucker trawl gear were towed obliquely from the surface to 10 m above the seafloor or to 200 m, whichever was shallower (Matarese et al., 2003; Dougherty et al.[3]). The bongo and Tucker trawl samplers have similar sampling effectiveness for ichthyoplankton (Shima and Bailey, 1994), so they were pooled into a common data index for subsequent species richness analyses. Net samples were preserved at sea in 5% formalin buffered with sodium borate and seawater. All samples were sorted for ichthyoplankton, identified to lowest possible taxonomic level, and enumerated at the Plankton Sorting and Identification Center in Szczecin, Poland using regional identification guides (Matarese et al., 1989; Ichthyoplankton Information System, available from https://apps-afsc.fisheries.noaa.gov/ichthyo/index.php, last update 14 June 2021). EcoFOCI scientists verified all identifications.

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[1] NMFS (National Marine Fisheries Service). 2020. Alaska geographic strategic plan 2020–2023, 20 p. NMFS, Silver Spring, MD. [Available from https://www.fisheries.noaa.gov/resource/document/alaska-geographic-strategic-plan-2020-2023, accessed on May 2022.]

[2] Orr, J. 2018. Personal commun. Alsk. Fish. Sci. Center, 7600 Sand Point Way NE, Seattle, WA 98115.

[3] Dougherty, A., C. Harpold, and J. Clark. 2010. Ecosystems and fisheries oceanography coordinated investigations (EcoFOCI) field manual. AFSC Processed Rep. 2010-02, 213 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA. [Available from https://www.fisheries.noaa.gov/resource/publication-database/alaska-fisheries-science-center-processed-reports.]

Species richness and data analysis

Species richness is a metric of biodiversity that can be used to detect and monitor the response of ecosystems to climate change (Gotelli and Colwell, 2001). This metric becomes more robust with enhanced taxonomic resolution. When EcoFOCI scientists make taxonomic advancements, archived specimens are re-identified to maintain taxonomically robust records for Alaska's ichthyoplankton.

Since we were most interested in examining species richness across years and regions, we did not account for areas or seasons with higher sampling intensity within each regional time series. To account for uneven sampling, sample-based rarefaction curves were used to examine changes in species richness in each Alaska LME using the *specaccum* function in the vegan package for R (Oksanen et al., 2020) and visualized using the ggplot2 package (Wickham, 2016; R Core Team, 2020). This approach depicts the number of unique taxa observed by the number of stations sampled each year without replacement. A locally estimated scatterplot smoothing (LOESS) function displayed the trendline and 95% confidence intervals for the time series in each LME.

Developmental series

Unlike adult fishes, who are often morphologically indistinguishable despite their size, early stages of fish development are dynamic, with small changes in size drastically altering their appearance and, consequently, the characters used to identify individuals to species. Therefore, an emphasis is placed on assembling developmental series and illustrating sizes with anatomy, meristics (counts of myomeres, fin rays, and spines), and pigmentation changes, which are particularly noticeable during transitions between flexion, post-flexion, and juvenile stages. Line drawings were created using a camera lucida affixed to a Wild M8 dissecting microscope (Wild Stereo Microscopes, now manufactured by Leica Microsystems Inc., Wetzlar, Germany). Due to formalin fixation, all pigment except melanistic pigment is lost. Therefore, only melanistic pigment was described and illustrated (Busby et al., 2017). Figures were prepared and finalized using Adobe Illustrator 2020 and Photoshop 2020 (Adobe Inc., San Jose, CA).

Results

Taxonomic resolution

The taxonomic resolution of the early life history stages of Alaska marine fishes has vastly improved since the 1970s, increasing from the descriptions of the eggs of 10 species and larvae of 52 species to describing the eggs of 44 species and larvae of 263 species with the publication of *Laboratory Guide to Early Life History Stages of Northeast Pacific Fishes* (Matarese et al., 1989; Busby et al., 2000) (Table 1). In the 1990s, most of the improvements in taxonomic resolution occurred within the genus *Sebastes* and the families Liparidae and Agonidae, bringing the number of species that could be identified in the larval stages to 291 (Busby et al., 2000) (Table 1). In the 2000s, additional research further increased the taxonomic resolution to include the larvae of 320 species (Matarese et al., 2011) (Table 1). Through the 2010s, EcoFOCI research culminated in the descriptions of the eggs of 127 species and larvae of 353 species (Table 1), with most of the recent contributions focused on the family Stichaeidae (Matarese et al., 2013) as well as flatfishes in the genera *Atheresthes* and *Limanda* (De Forest et al., 2014; Busby et al., 2017).

Patterns of species richness

Of the 3 LMEs, the Gulf of Alaska had the longest time series (1972–2021), followed by the southeastern Bering Sea (1979–2019) and the Arctic (Chukchi and Beaufort seas; 2004–2019).

Species richness in the Gulf of Alaska increased from the 1970s to mid-1980s and reached an asymptote of 70 species by the late 1980s. It remained relatively stable through 2021, with a peak in 2013 of 86 species (Fig. 1A). In contrast, species richness in the southeastern Bering Sea increased from 1979 to a peak of 79 species in 2013 and then declined rapidly to a minimum of 20 species in 2018 (Fig. 1B). Though fewer years were available to analyze, species richness in the Arctic has appeared to remain relatively consistent over the time series, with a maximum of 33 species in 2009 and a minimum of 13 species in 2014 (Fig. 1C).

Updates to developmental series

Juvenile Arctic cod (*Boreogadus saida*) (Gadidae) can be easily confused with similar-sized individuals of another gadid, *Gadus chalcogrammus*. Juvenile *B. saida* (21.5 mm standard length [SL]) are more slender than *Gadus chalcogrammus,* have a slight narrowing of the caudal peduncle, and are more heavily pigmented (Fig. 2). However, the most reliable diagnostic character is the lack of pigment along the isthmus, which is present in *Gadus chalcogrammus*, and first becomes present in the larval stage.

All previous illustrations of Arctic staghorn sculpin (*Gymnocanthus tricuspis*) (Cottidae) originated from a narrow developmental series collected in the North Atlantic (Khan, 1972). However, with an increased presence of EcoFOCI in the Arctic in recent years, an early juvenile (23.0 mm SL) from the Chukchi Sea was contributed to the developmental series (Fig. 3A). Medio-lat-

Table 1

Temporal patterns of described biodiversity of the fishes of Alaska with known marine early life history stages (eggs through juveniles) based on the list of species in Mecklenburg et al. (2002). The total number of valid species (495) is adjusted for recent taxonomic advances, currently recognized but undescribed species, and documented marine stages. The total number of valid species was used to calculate the percent of known eggs and larvae. Blank spaces denote no reliable records or publications found to quantify taxonomic advances for a decade, likely due to the primary focus on the identification of walleye pollock (*Gadus chalcogrammus*) eggs prior to 1998.

Decade	Number of described eggs	Percent eggs known	Number of described larvae	Percent larvae known
1970s	10	2.0	52	10.5
1980s	44	8.9	263	53.1
1990s			291	58.8
2000s	127	25.7	320	64.6
2010s	127	25.7	353	71.3

eral pigment is more prominent in juvenile *Gymnocanthus tricuspis* than in younger specimens, as is head pigment, particularly along the dorsum and on the opercle. In addition, pigment bands are present in the membranes of the dorsal and anal fins, in the centers of the first and second sections of the dorsal fin, and posteriorly in the anal fin (Fig. 3A).

Another cottid, ribbed sculpin (*Triglops pingelii*), is identified using a combination of meristics and the earlier appearance of robust head spines relative to the other 3 described *Triglops* species (Blood and Matarese, 2010). An early juvenile *T. pingelii* (25.0 mm SL) (Fig. 3B) highlighted the characters needed to distinguish this species from the other *Triglops* species after juvenile transformation. In the early larval stages, *T. pingelii* is most likely to be confused with scissortail sculpin (*T. forficatus*) due to the presence of postanal ventral melanophores in both species. However, *T. pingelii* develops nasal, parietal, and epioccipatal head spines during the juvenile stage (about 25 mm SL) (Fig. 3B) that are lacking in similar-sized *T. forficatus*. In addition, *T. pingelii* has increased head pigmentation, especially along the upper and lower jaws and the opercular series, compared to *T. forficatus*. Furthermore, *T. pingelii* develops 4 pigment bands that extend from the dorsal midline to below the lateral line medio-laterally, which are also lacking in *T. forficatus*.

The stichaeid Arctic shanny (*Stichaeus punctatus*) is another species where the current illustrated developmental series is missing a juvenile illustration (Fig. 4A). The illustrated early juvenile *Stichaeus punctatus* (30.0 mm SL) retains the hypaxial pigmentation characteristic of the larvae. However, it is more heavily pigmented along the dorsal part of the head and develops a faint medio-lateral stripe (Fig. 4A). At the juvenile stage, the anal fin is fully formed and the lack of spines posteriorly distinguishes *Stichaeus punctatus* (absent) from the fourline snakeblenny (*Eumesogrammus praecisus*) (present).

The lesser prickleback (*Alectridium aurantiacum*) is a stichaeid found in the Bering Sea, and the EcoFOCI field program does not encounter it regularly. When preparing a guide to stichaeids of the northeast Pacific Ocean and Bering Sea, *A. aurantiacum* specimens were examined but not added to the AFSC Ichthyoplankton Information System (IIS) because there was only one illustration of a single post-flexion specimen (Matarese et al., 2013). However, a 9.9-mm-notochord length (NL) pre-flexion individual (Fig. 4B) was recently illustrated, creating a developmental series, albeit a limited one. Similar to *Stichaeus punctatus* and *E. praecisus*, *A. aurantiacum* has hypaxial pigment and a series of dorsal gut melanophores. However, like other Xiphisterinae, *A. aurantiacum* lacks pelvic fins, which becomes evident at the juvenile stage (Matarese et al., 2013). Pigment is present dorsally on the head and along the full length of the gut in pre-flexion *A. aurantiacum,* which is not present in similar-sized *Stichaeus punctatus*.

An 8.0-mm-NL specimen of the family Pleuronectidae, Alaska plaice (*Pleuronectes quadrituberculatus*) (Fig. 5A), contributes an updated illustration of the flexion stage, advancing previous illustrations of similar-staged individuals by Pertseva-Ostroumova (1961). The specimen is also more useful for identification than the 6.3-mm-NL pre-flexion specimen featured in the IIS and Matarese et al. (1989). During flexion, pigment in the anal finfold becomes less apparent than it is in earlier life stages, but the reduced or absent hypaxial pigment and lack of urostyle pigment remain diagnostic for this species. Larval *Pleuronectes quadrituberculatus* can be easily confused with yellowfin sole (*Limanda aspera*), but *Pleuronectes quadrituberculatus* has a narrower body

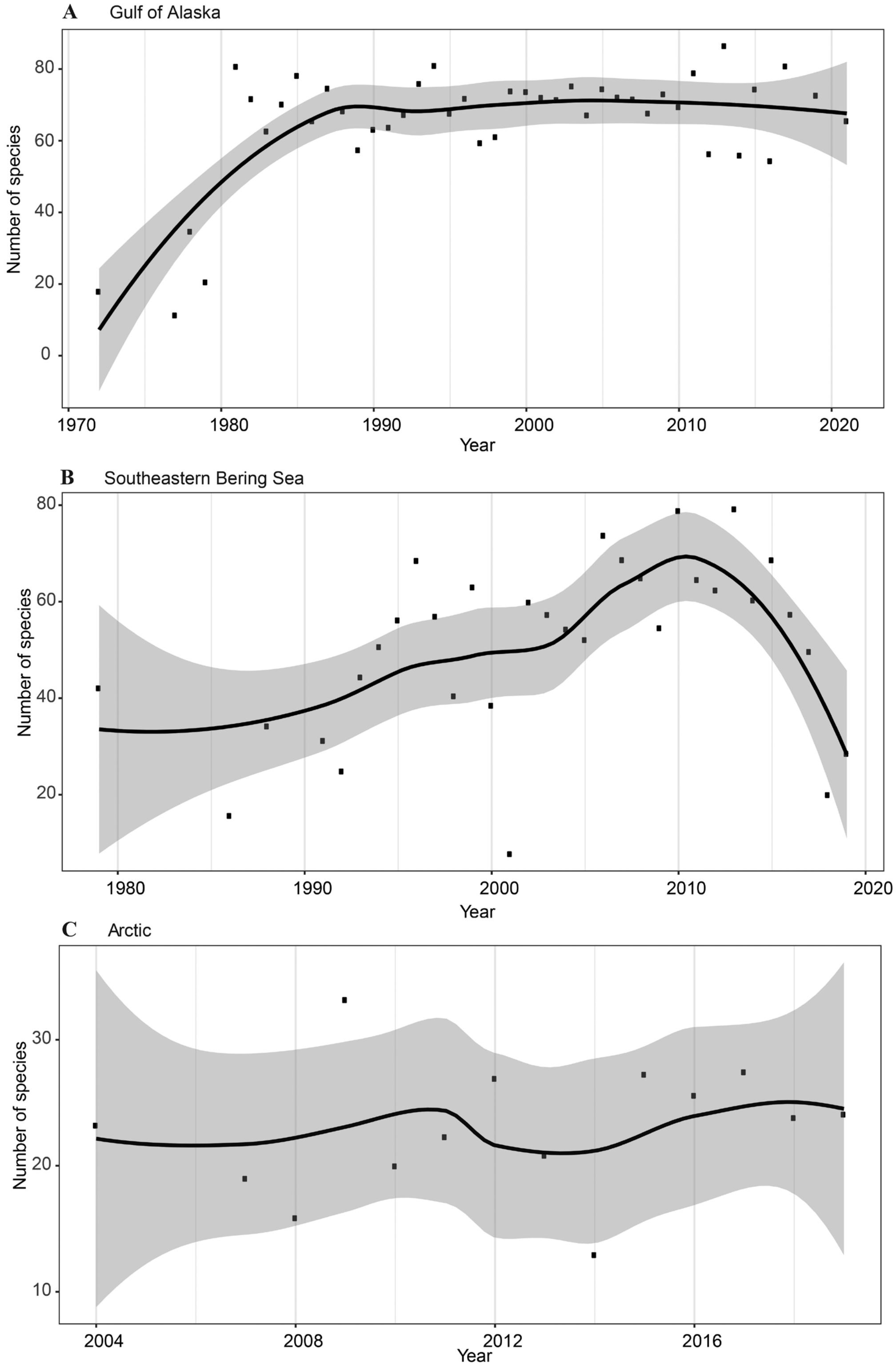

Figure 1

Rarefied species richness for the large marine ecosystems of Alaska: (**A**) Gulf of Alaska (1972–2021), (**B**) southeastern Bering Sea (1979–2019), and (**C**) Arctic (Chukchi and Beaufort Seas, 2004–2019). The solid line is the time series mean, and the shaded area represents a 95% confidence interval. Please note the scale on the axes differ among panels.

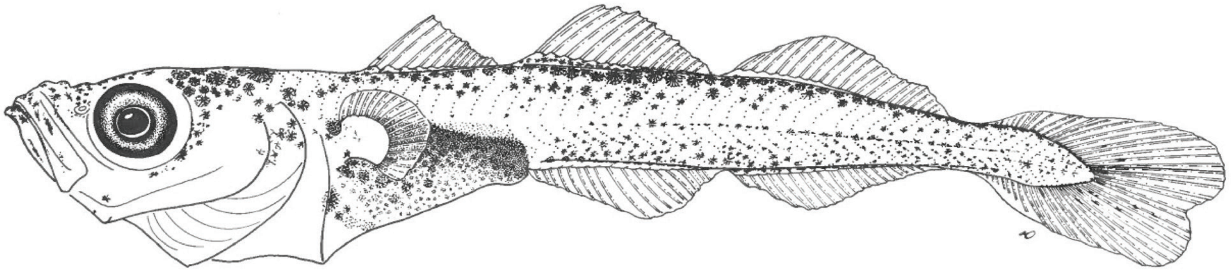

Figure 2

Illustration of a 21.5-mm-standard length juvenile Arctic cod (*Boreogadus saida*) collected in the Chukchi Sea on 29 August 2013.

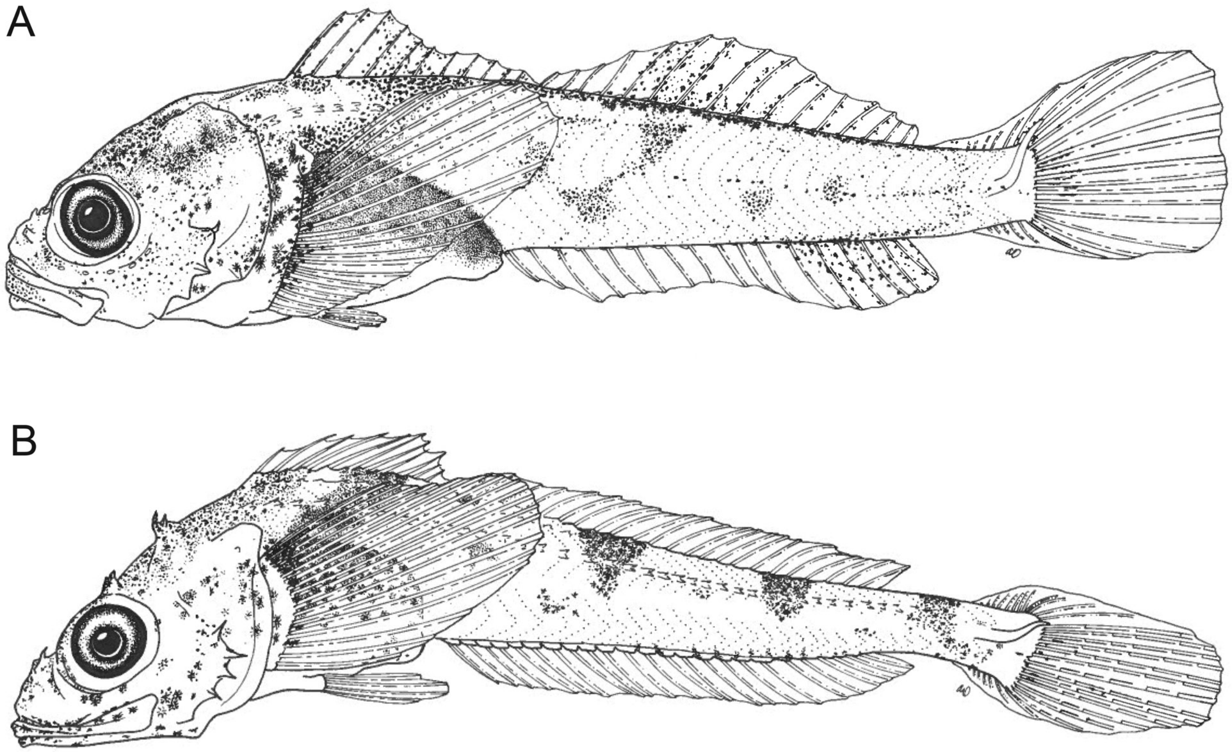

Figure 3

Illustrations of 2 juveniles from the family Cottidae: (**A**) Arctic staghorn sculpin (*Gymnocanthus tricuspis*) (23.0 mm standard length [SL]) collected in the Chukchi Sea on 2 September 2013 and (**B**) ribbed sculpin (*Triglops pingelii*) (25.0 mm SL) collected by Ecosystems and Fisheries-Oceanography Coordinated Investigations Program's sampling program in the southeastern Bering Sea or western Gulf of Alaska between 1979 and 2018.

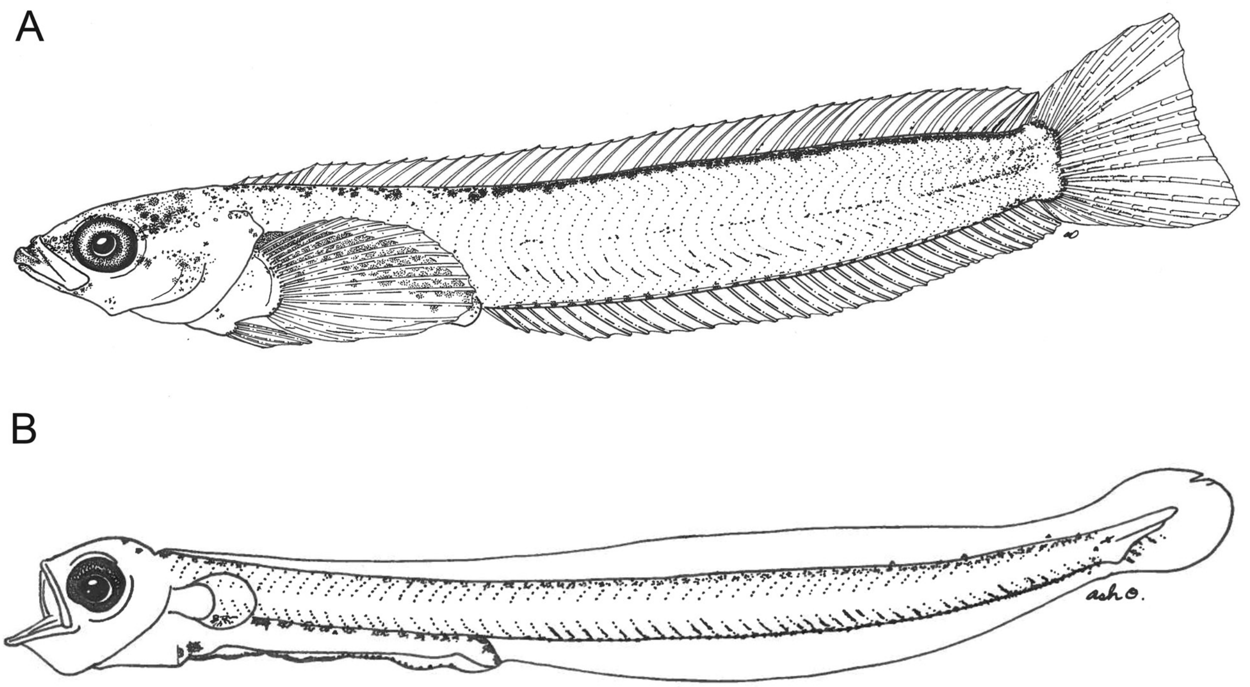

Figure 4

Illustrations of (**A**) a juvenile Arctic shanny (*Stichaeus punctatus*) (30.0 mm standard length) collected in the Chukchi Sea on 29 August 2012 and (**B**) a larval lesser prickleback (*Alectridium aurantiacum*) (9.9 mm notochord length) collected along the outer shelf of the southeastern Bering Sea on 29 May 2012.

and possesses external dorsal pigment along the caudal peduncle that is lacking in *Limanda aspera*.

Another pleuronectid, starry flounder (*Platichthys stellatus*), undergoes transformation earlier than many flatfish species (completed by 10 mm SL), lacks dorsal midline pigment, and is relatively deep-bodied. An 8.8-mm post-flexion *Platichthys stellatus* was illustrated to document the changes that occur during eye migration in the right-eyed variant common to the northeast Pacific Ocean (Fig. 5B). Okiyama (2014) presents a similarly sized and staged specimen of the left-eyed variant common in the western Pacific Ocean. As the eye migrates, *Platichthys stellatus* is diagnosable by the presence of pigment in the caudal fin, especially in the developing anal fin (Fig. 5B). At this stage, most of the pigment is present laterally below the lateral line, although dorsolateral pigment becomes more prominent after the eye completes migration.

Pertseva-Ostroumova (1961) first illustrated and described the larval stages of a third pleuronectid, Arctic flounder (*Liopsetta glacialis*). The developmental series was limited to a narrow size range and poor quality. A 4.8-mm-NL individual improved upon those original illustrations by representing the position of melanistic pigment relative to myomeres (Fig. 5C). The ventral margin of the gut is heavily pigmented with stellate pigment. The body is more heavily pigmented posteriorly, and pigment extends around the urostyle. The body is unpigmented anteriorly to approximately myomere 9, where ventral midline pigment starts at the anus. Dorsal midline pigment begins at approximately myomere 18, followed by medio-lateral pigment at myomere 23 (Fig. 5C).

Discussion

Taxonomic resolution

Taxonomic resolution and systematics of the early life stages of Alaska marine fishes has advanced rapidly since 1981 when *Gadus chalcogrammus* larvae were indistinguishable from other larval gadids (Collette and Vecchione, 1995), precluding research into recruitment dynamics for the most commercially important, exploited species in Alaska. Since then, due to the work of EcoFOCI taxonomists at AFSC and Morski Instytut Rybacki in Poland, we have made great strides in the taxonomic resolution of fish larvae and eggs of the LMEs around

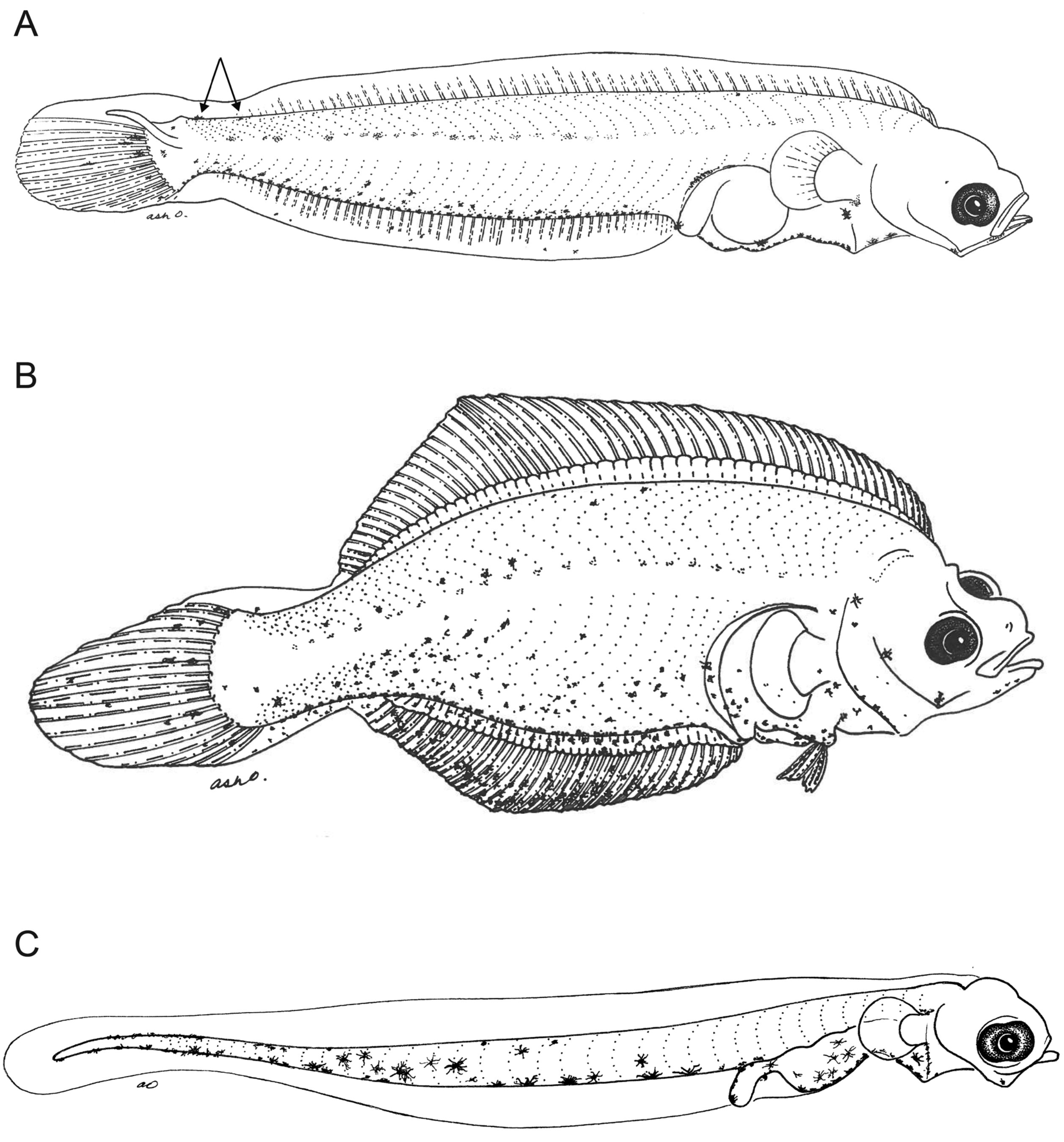

Figure 5

Illustrations of (**A**) a larval Alaska plaice (*Pleuronectes quadrituberculatus*) (8.0 mm notochord length [NL]) collected in the western Gulf of Alaska on 6. June 6, 2011, (**B**) a juvenile starry flounder (*Platichthys stellatus*) (8.8 mm standard length) collected in the Gulf of Alaska, Chignik Bay on July 25, 1991, and (**C**) a larval Arctic flounder (*Liopsetta glacialis*) (4.8 mm NL) collected in the Chukchi Sea on June 21, 2017. Arrows on panel A highlight the external dorsal pigment present along the caudal peduncle that is a diagnostic character for *Pleuronectes quadrituberculatus* and distinguishes it from the yellowfin sole (*Limanda aspera*).

Alaska. Between 1979 and 1998, only the eggs of *Gadus chalcogrammus* were identified and classified according to developmental stage (Busby et al., 2000). Therefore, the taxonomic resolution of eggs is less robust than the larval and juvenile stages. However, EcoFOCI consistently describes, identifies, and records fish eggs to species in a digital database and IIS, providing abundance and distribution data for a life stage that is understudied in many ecosystems but can provide valuable information regarding spawning stock biomass and the condition and size of spawners (Trippel and Neil, 2004; Paulsen et al., 2009 and references therein). Now, 26% of eggs and 71% of larvae of Alaska marine taxa can be identified thanks to continuous updates to developmental series (Busby et al., 2017), integration of traditional identification techniques with molecular tools (De Forest et al., 2014), and the dissemination of this information digitally through the IIS, which makes the data freely accessible to users around the globe (Leis, 2015). Despite our taxonomic advances, there are still several taxa that need further research to identify their early life history stages, particularly snailfishes in the genus *Liparis*, cottids in the genera of *Gymnocanthus*, *Icelus*, *Icelinus*, and *Myoxocephalus*, and rockfishes in the genus *Sebastes*. Although distinct from other taxa, rockfish larvae lack diagnostic characters to distinguish among many of the species (Kendall, 2000), representing a promising application for environmental DNA and other molecular tools to provide species-level information (Thompson et al., 2017).

Patterns of species richness

Future studies should investigate the association between patterns of species richness and environmental factors in Alaska's LMEs that are sensitive to climate change (marine heatwaves, cold pool extent, sea ice extent). For example, the rapid increase in the species richness observed in the Gulf of Alaska in the 1970s to an asymptote in the late 1980s corresponds to a regime shift that occurred in the 1970s when a cold-water community transitioned to a warm-water community due to a shift in the location and intensity of the Aleutian Low (Anderson and Piatt, 1999). Additionally, the 2014–2016 marine heatwave impacted spring species richness in the Gulf of Alaska (Nielsen et al., 2021), further highlighting the need for taxonomically robust datasets to detect and monitor the impacts of climate change and support climate-ready fisheries.

Updates to developmental series

With the increased interest in the Arctic due to rapid warming and potential perturbations to species' distributions, there is an increased need to maintain and validate high taxonomic accuracy. Adult *Gadus chalcogrammus* have moved into the northern Bering Sea in warm years (Stevenson and Lauth, 2019), increasing the potential for confusion of the early stages of this species with Arctic gadids like *B. saida*. The illustration of *B. saida* (21.5 mm SL) presented here allows for a direct comparison of *B. saida* to *Gadus chalcogrammus* juveniles. This will allow fisheries biologists to accurately resolve the distribution and abundance of each species in the northern Bering Sea and Chukchi Sea and reduce misidentifications in the field by providing morphological diagnostic characters (Wildes et al., 2022).

As more specimens become available, developmental series are updated with larvae and juveniles that display taxonomically informative characters. Such is the case with *Liopsetta glacialis,* a coastal Arctic flatfish whose biology and ecology are poorly known due to an incomplete developmental series. We have added more detail to aid in successfully identifying larval specimens of *Liopsetta glacialis*. The description of pelvic fin presence in juvenile *Stichaeus punctatus* is a useful character that differentiates it from the otherwise similar *A. aurantiacum*. We provide additional tools to support future ecological studies of fishes in the dynamic Arctic ecosystem by completing more developmental series that highlight the main morphological diagnostic characters.

Another core mission of EcoFOCI's commitment to improving our taxonomic resolution of early life history stages of Alaskan fishes is to make this information freely available to stakeholders. In the early 2000s, the publication of an atlas of abundance and distribution of ichthyoplankton in the northeast Pacific Ocean (Matarese et al., 2003) emphasized the need for an updated laboratory guide (Matarese et al., 1989). Instead of assembling a static guide, EcoFOCI integrated the information from the atlas and the laboratory guide to build the digital, freely accessible IIS, which is updated regularly as new life history information, abundance and distribution data, and illustrations become available (Blood et al.[4]). The illustrations and descriptions presented here will be contributed to the IIS since updates are vital to ensure its utility to researchers. The IIS supports ecosystem and process-mediated research into recruitment dynamics by making the most current diagnostic materials to advance species identification in the northeast Pacific accessible.

Conclusions

This manuscript summarizes the advancements in the taxonomic resolution of the early life history stages of

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[4] Blood, D. M., A. C. Matarese, and W. C. Rugen. 2006. Ichthyoplankton information system: taxonomy, distribution, and abundance of early life history stages of marine fishes in the northeast Pacific Ocean and Bering Sea. AFSC Q. Rep. 2006, Apr.–Jun., 11 p. Alsk. Fish. Sci. Center, Seattle, WA. [Available from https://apps-afsc.fisheries.noaa.gov/Quarterly/amj2006/amj06.htm.]

fishes in Alaska's LMEs made since 2000 (Busby et al., 2000), explores patterns of species richness, and contributes new illustrations and descriptions to the developmental series of 8 species with incomplete developmental series. With the uncertainty of how ecosystems and communities will respond to changing environmental conditions in Alaska (e.g., loss of sea ice, more frequent marine heatwave events), higher resolution taxonomic data provide a better understanding of how commercially and ecologically important fish populations may respond to these changes at the species level across life stages. Key life history transitions may represent survival bottlenecks that influence the number of individuals recruited into fisheries (Miller and Kendall, 2009; Doyle and Mier, 2016). Therefore, being able to identify such individuals reliably before and after life history transitions is crucial for generating accurate abundance estimates that are provided to various stock assessment tools (e.g., ecosystem status reports, ecosystem and socioeconomic profiles, risk tables, essential fish habitat descriptions) in support of ecosystem-based fisheries management in Alaska.

Acknowledgments

We thank the Morski Instytut Rybacki Plankton Sorting and Identification Center in Szczecin, Poland for their taxonomic expertise that makes studies of the ecology of ichthyoplankton possible. We also want to thank those who provided constructive comments on earlier versions of this manuscript. This is EcoFOCI contribution number EcoFOCI-1049. To Sookie, my best writing partner for so many years.

Author contributions are as follows: A. L. Deary conceptualized the project, led analyses, and generated the manuscript and figures; M. S. Busby and J. Barrett provided taxonomic expertise and writing assistance; K. E. Axler assisted in analysis and writing as well as providing taxonomic expertise; and A. Overdick was the illustrator and provided writing assistance.

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Cite as: Deary, Alison L., Morgan S. Busby, Jenna Barrett, Kellia E. Axler, and Ashlee Overdick. 2024. Advancements in ichthyoplankton taxonomy in the large marine ecosystems of Alaska: 1979–2021. *In* Early Life History and Biology of Marine Fishes: Research inspired by the work of H Geoffrey Moser (J. M. Leis, W. Watson, B. C. Mundy, and P. Konstantinidis, guest eds.), p. 155–166. NOAA Professional Paper NMFS 24. https://doi.org/10.7755/PP.24.12