An unusual gelatinous plankton event in the NE Pacific: The Great Pyrosome Bloom of 2017

by Richard Brodeur, Ian Perry, Jennifer Boldt, Linnea Flostrand, Moira Galbraith, Jacquelynne King, James Murphy, Keith Sakuma and Andrew Thompson

In the winter of 2016, and continuing into summer 2017, people exploring the open ocean beaches of northwestern North America were surprised and puzzled to find strange gelatinous creatures littering the shoreline. These creatures turned out to be colonies of the pelagic tunicate *Pyrosoma atlanticum* (Fig. 1). This species is common in warm open ocean waters throughout the tropics, but along the west coast of North America it has been common only as far north as southern California, and is rarely seen north of the state. However, in the past year these tropical tunicates were highly abundant in the waters from Oregon to British Columbia, and occurred in scientific samples as far north as the Gulf of Alaska. In this report, we examine the magnitude and extent of this anomalous event in the NE Pacific, suggest possible causes, and describe some potential ecosystem implications of this bloom.

*Fig. 1 A) Close-up of pyrosomes caught in the Gulf of Alaska; B) a large catch of pyrosomes from a pelagic survey off Oregon, C) pyrosomes on a beach off Oregon in November 2017, and D) medusafish (*Icichthys lockingtoni,*) found in the body cavity of a pyrosome caught in pelagic surveys off California.*

What are pyrosomes?

Pyrosomes (Greek for "fire bodies" because of their bioluminescence) are a small group of pelagic tunicates, of which eight species in three genera have been described worldwide. They are colonial, with each colony comprising thousands of individual clones encased in a rigid gelatinous 'tunic' that is open at one end (Hirose *et al*., 2001). Individuals draw water from the outside surface and release water into the hollow core of the colony. This provides the colony with a type of hydrostatic 'skeleton' and the means for jet propulsion. Although individual pyrosomes are small (mm in size), their colonies can reach lengths of several meters; the species of this NE Pacific event is known to reach over 80 cm in length. Colonies undertake diel vertical migrations, sometimes over 700 m depth (Anderson and Sardou, 1994), and have among the highest phytoplankton clearance rates of any zooplankton grazer (Perissinotto *et al*., 2007). It has been suggested that internal lipid accumulation by pyrosomes is limited, with colonies instead using their food intake to drive high biomass turnover (Perissinotto *et al*., 2007).

The 2017 Pyrosome event in the NE Pacific

Over the past three decades, *P. atlanticum* had occurred regularly in offshore midwater trawl surveys off southern California, but in 2012 there was a notable increase in their numbers coincident with large abundances of salps (another pelagic tunicate) (Wells *et al*., 2017). While their numbers in 2013 were much reduced, pyrosome abundance dramatically increased in 2014 and 2015 resulting in them being the dominant organism collected off the shelf break of California (Sakuma *et al*., 2016). Starting in June 2014, they occurred in pelagic trawl surveys in offshore waters of southern Oregon, moving progressively northward in the summer of 2015 and 2016, but still in waters off the shelf break. Collections were made using near-surface or midwater trawls from research surveys conducted by the National Marine Fisheries Service (NMFS), NOAA and Fisheries and Oceans Canada (DFO) from May through September of 2017 from southern California to the northern Gulf of Alaska (Fig. 2). *Pyrosoma atlanticum* was found at most sampled stations in these surveys, including high catches on the continental shelf and close to shore. Densities in some trawls were extraordinary, exceeding 60,000 kg/km^3 at locations off Oregon, over 200,000 kg/km^3 off Vancouver Island, and over 150 kg/km^3 off SE Alaska (Fig. 2). Catches were often so high that research nets were ripped open due to the high biomass, and some stations easily sampled in previous years had to be aborted in 2017. The varying catch rates demonstrate that the distributions of pyrosomes were not continuous along the continental shelf, but that they tended to occur in clusters, possibly associated with specific oceanographic conditions (currently under investigation).

Routine plankton surveys along the continental shelf of Vancouver Island began to collect pyrosome individuals (less than 5 mm in length) and small colonies (greater than 4 cm in length) in spring and summer 2016. By February 2017, plankton surveys were catching pyrosome colonies up to 15 cm in length from the continental shelf along the west coast from Oregon to Vancouver Island. By late spring and summer 2017, the pyrosome event was in full bloom, with very high abundances and large colonies occurring from California to Alaska and into the central NE Pacific, including over open ocean seamounts.

Potential implications of this pyrosome event

The causes of this extraordinary event are unknown. Individuals may have been advected into the NE Pacific during the marine heat wave of 2014–2015 and the strong El Niño in early 2016. They may have found an environment in transition between these very warm conditions and a return to normal conditions in 2017, which provided sufficiently warm temperatures and ample food for their growth and reproduction to accelerate. The causes of this event remain under investigation but recent (November 2017) observations of small pyrosomes washing up on west coast beaches similar to those seen in the winter of 2016/2017 suggest that conditions may be favorable for another bloom in the summer of 2018 (Fig. 1).

Pyrosome colonies were visible at the surface, and coated oceanographic sampling gear and clogged fishing nets and hooks throughout this region. Substantial negative impacts have been reported on many different commercial and sport fishing operations from Oregon to SE Alaska, including salmon troll, shrimp and fish bottom trawl gear (Fig. 3A). Estimates of the economic impact of this bloom on lost or spoiled fisheries are not available but anecdotal reports suggest that they may have a substantial negative impact to coastal fisheries of the NE Pacific.

The impacts of this event to the marine ecosystems of the NE Pacific are also being studied. Such a high biomass of easily captured prey has obvious potential for marine predators and integration into the food webs of high trophic levels. However, the low accumulation of lipid stores in pyrosomes (Perissinotto *et al*., 2007) suggests that they may be a sub-optimal prey item. Studies of pyrosomes in their normal tropical habitats show that numerous fishes, seabirds, and marine mammals can consume pyrosomes (Harbison, 1998). Fishers along the west coast of North America during the peak of this event reported finding pyrosomes in the stomachs of Pacific halibut, rockfishes, sablefish, and other demersal fish species, and in juvenile and adult Pacific salmon and other pelagic forage fishes (Brodeur *et al*., in press). A beached fin whale in Washington State had numerous pyrosomes in its stomach (Fig. 3C). Pyrosomes have also been observed in the NE

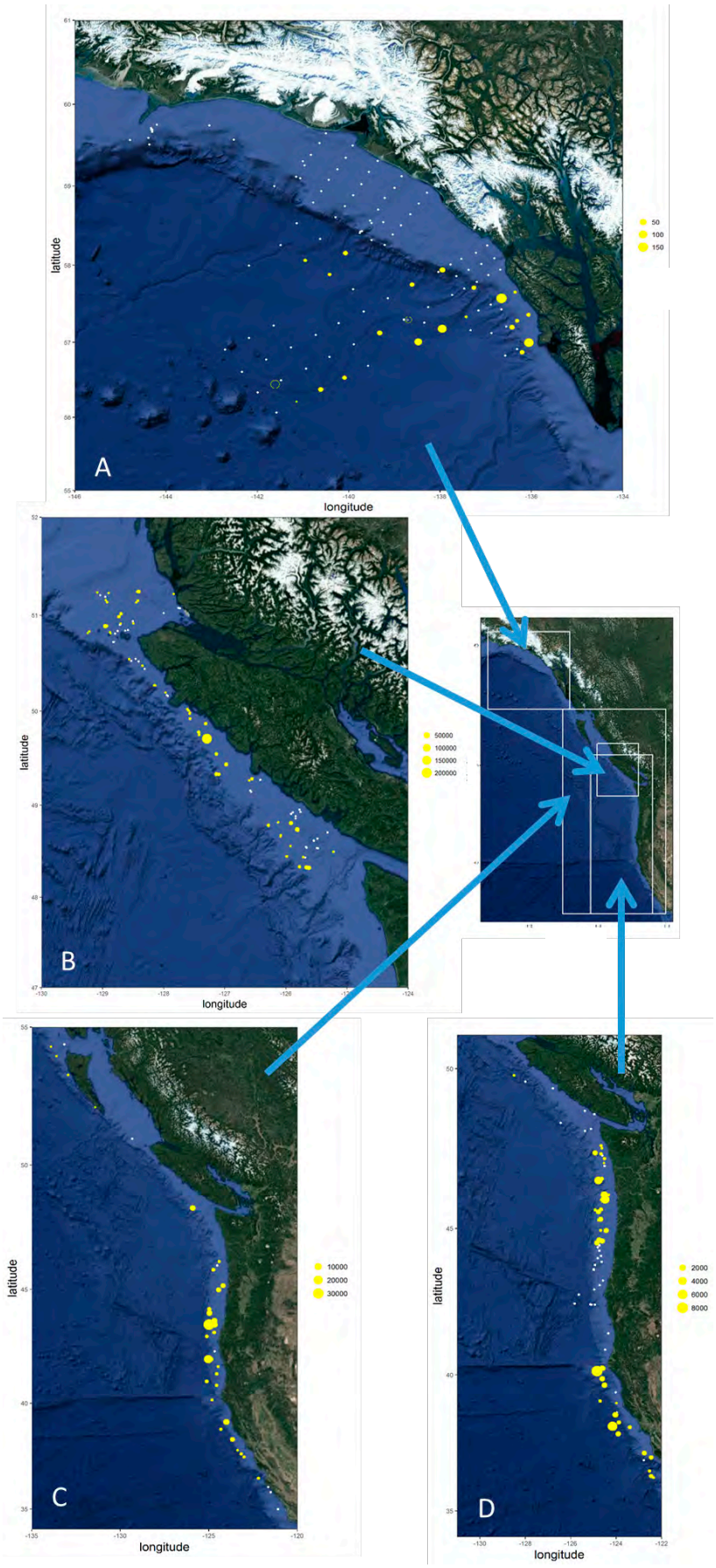

Fig. 2 *Distribution and density (kg km^{-3}) of pyrosomes from A) NMFS Gulf of Alaska surveys during summer of 2017 (July 4–August 16, 2017). B) DFO integrated pelagic ecosystem survey (July 19–August 2, 2017), C) NMFS coastal pelagic fish survey (June 25–August 9), and D) NMFS coastwide Pacific hake survey (June 26–September 6, 2017; data courtesy of NWFSC FEAT group). Inset shows relative locations of the panels in the Northeast Pacific Ocean. White dots depict samples without pyrosomes and yellow circles are scaled by pyrosome density (note that the scale differs in each plot). In panel A, solid circles are from surface trawls and open circles from midwater trawls.*

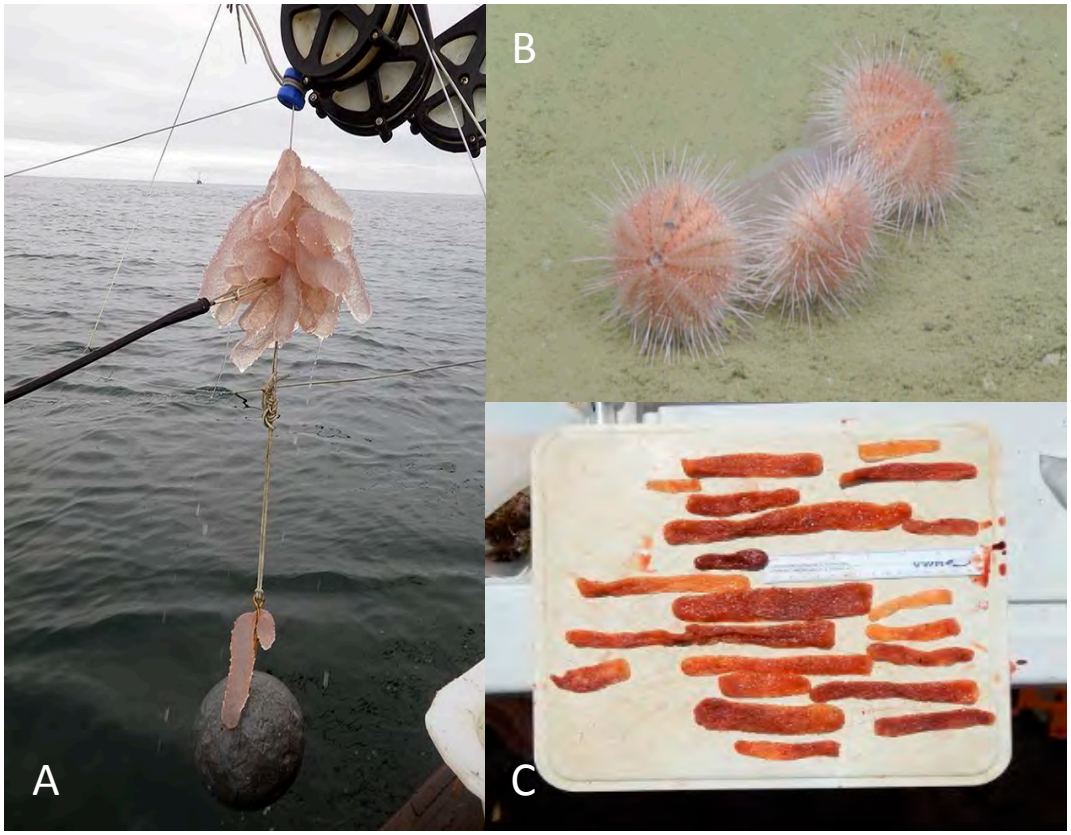

Fig. 3 A) Pyrosomes caught on salmon fishing gear off British Columbia, B) pyrosomes being consumed by sea urchins (photo taken by ROV Hercules in Quinault Canyon, off Washington State, courtesy of Ocean Exploration Trust), and C) pyrosomes taken from stomach of fin whale (courtesy Jessie Huggins, Cascadia Research, Olympia, WA).

Pacific being eaten by benthic animals such as sea anenomes, crabs, sea urchins and sea stars (Archer *et al*., in Press), even at bottom depths of several hundred meters (Fig. 3B). The impacts of these very high biomasses of pyrosomes that die and sink to the bottom, drawing down oxygen concentrations as they decompose, is unknown, but the die-off of these blooms has the potential to provide a substantial input of carbon to the benthic food web (Lebrato and Jones, 2009). An additional positive effect has been the observation that some pelagic fishes (medusafish and juvenile rockfish) have been seen living inside the tubes of pyrosomes and potentially consuming part of the pyrosomes in coastal waters (Fig. 1D), thus providing a possible pelagic refugium from predation and source of food for these fishes (Janssen and Harbison, 1981).

Previous work on the feeding of *P. atlanticum* in tropical waters has found a preference for phytoplankton cells greater than 10 µm in diameter (*Perissinotto et al*., 2007). The diet composition of this species in the more productive coastal waters of the NE Pacific is unknown but several studies are underway to examine this. The very high filtration rates may also reduce phytoplankton biomass locally when abundances of pyrosomes are very high (Drits *et al*., 1992), although how extensive this grazing pressure may have been in 2017, and its implications for coastal productivity during the NE Pacific event, are presently unknown, but warrant further investigation.

Conclusions

In the past few years, anomalous ocean conditions in the NE Pacific, including the marine heat wave (Bond *et al*., 2015; Di Lorenzo and Mantua, 2016), have been accompanied by unusual occurrences of species (Perry *et al*., 2017). Some of these occurrences were isolated events (*e.g*., first ever record of a Pacific angel shark in British Columbia waters in 2016; Perry *et al*., 2017); whereas, others are broad both spatially and temporally, such as the extended toxic algae blooms and consequent marine mammal deaths in 2015 (McCabe *et al*., 2016). The 2016-2017 bloom of pyrosomes was also a large-scale event and is expected to last into 2018. Both positive and negative impacts of the pyrosomes are expected to occur, however, the cumulative impacts of this event are not known but are presently being investigated in different laboratories along the west coast of North America. There is more to learn about how ocean conditions are linked to these events and the implications of these blooms on the trophodynamics of the Northeast Pacific marine ecosystems. Projected climate change in the coming decades may lead to anomalous events such as the pyrosome bloom becoming more common in the future, requiring continuing monitoring to assess its impacts.

References

Andersen, V., Sardou, J. (1994) *Pyrosoma atlanticum* (Tunicata, Thaliacea): diel migration and vertical distribution as a function of colony size. J. Plankton Res. 16: 337–349.

Archer, S.K., Kahn, A.S., Leys, S.P., Norgard, T., Girard, F., Du Preez, C., Dunham, A. (In press) Pyrosome consumption by benthic organisms during blooms in the NE Pacific and Gulf of Mexico. Ecology.

Bond, N.A., Cronin, M.F., Freeland, H., Mantua N. (2015) Causes and impacts of the 2014 warm anomaly in the NE Pacific, Geophys. Res. Lett. 42: 3414–3420, doi:10.1002/2015GL063306.

Brodeur, R.D., Hunsicker, M.E., Hann, A., Miller, T.W. (In press) Effects of warming ocean conditions on feeding ecology of small pelagic fishes in a coastal upwelling ecosystem: a shift to gelatinous food sources. Mar. Ecol. Prog. Ser.

Di Lorenzo, E., Mantua, N. (2016) Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change, published online: 11 July 2016 DOI:10.1038/nclimate3082.

Drits, A.V., Arashkevich, E.G., Semenova, T.N. (1992) *Pyrosoma atlanticum* (Tunicata, Thaliacea): grazing impact on phytoplankton standing stock and role in organic carbon flux. J. Plankton Res. 14: 799–809.

Harbison, G.R. (1998) The parasites and predators of Thaliacea. In: Bone Q. (Ed.) The biology of pelagic tunicates. Oxford University Press, Oxford, pp. 187–214

Hirose, E., Ohshima, C., Nishikawa, J. (2001) Tunic cells in pyrosomes (Thaliacea, Urochordata): cell morphology, distribution, and motility. Invert. Biol. 120: 386–393.

Janssen, J., Harbison, G.R. (1981). Fish in salps: the association of squaretails (*Tetragonurus* spp.) with pelagic tunicates. J. Mar. Biol. Assoc. U.K. 61: 917–927.

Lebrato, M., Jones, D.O.B. (2009) Mass deposition event of *Pyrosoma atlanticum* carcasses off Ivory Coast (West Africa). Limnol. Oceanogr. 45: 1197–1209.

McCabe, R.M., Hickey, B.M., Kudela, R.M., Lefebvre, K.A., Adams, N.G., Bill, B.D. Gulland, F.M.D., Thomson, R.E., Cochlan, W.P., Trainer, V.L. (2016) An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions, Geophys. Res. Let. 43: 10,366–10,376, doi:10.1002/2016GL070023.

Perissinotto, R., Mayzaud, P., Nichols, P.D., Labat, J.P. (2007) Grazing by *Pyrosoma atlanticum* (Tunicata Thaliacea) in the south Indian Ocean. Mar. Ecol. Progr. Ser. 330: 1–11.

Perry, R.I., King, S., Boldt, J., Chandler, P. (2017) Unusual events in Canada's Pacific marine waters in 2016. In Chandler, P., King, S., and Boldt, J. (Eds.) State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3225: 243 + vi pp.

Sakuma, K.M., Field, J.C., Mantua, N.J., Ralston, S., Marinovic, B.B., Carrion, C.N. (2016) Anomalous epipelagic micronekton assemblage patterns in the neritic waters of the California Current in Spring 2015 during a period of extreme ocean conditions. Calif. Coop. Ocean. Fish. Invest. Rep. 57: 163–183.

Wells, B.K., Schroeder, I.D., Bograd, S.J., Hazen, E.L., Jacox, M.G., Leising, A., Mantua, N., Santora, J.A., Fisher, J., Peterson, B., Bjorkstedt, E., Robertson, R.R., Chavez, F.P., Goericke, R., Kudela, R., Anderson, C., Lavaniegos, B.E., Gomez-Valdes, J., Brodeur, R.D., Daly, E.A., Morgan, C.A., Auth, T.D., Field, J., Sakuma, K., Mcclatchie, S., Thompson, A.R., Weber, E.D., Watson, W., Suryan, R.M., Parrish, J., Dolliver, J., Loredo, S., Porquez, J.M., Zamon, J.E., Schneider, S.R., Golightly, R.T., Warzybok, P., Bradley, R., Jahncke, J., Sydeman, W., Melin, S.R., Hildebrand, J., Debich, A.J., Thayre, B. (2017) State Of The California Current 2016–17: Still anything but "normal" in the North. CALCOFI Rep, 58: 1–55.

Dr. Richard Brodeur (Rick.Brodeur@noaa.gov) is a Research Fisheries Oceanographer working in the Fish Ecology Division of the Northwest Fisheries Science Center, NOAA Fisheries, based in Newport (Oregon, U.S.A.). Ric began his career working on early life history and recruitment dynamics of walleye pollock in the Gulf of Alaska and Bering Sea for the Alaska Fisheries Science Center and became interested in jellyfish following their dramatic increase in that ecosystem. He has published on a variety of topics ranging from satellite oceanography to fisheries acoustics, but has focused much of his research on feeding and food web interactions in the pelagic ecosystem. Ric has been heavily involved in PICES, serving on several committees and expert groups and organizing a number of topic sessions and workshops at past Annual Meetings.

Dr. Ian Perry (Ian.Perry@dfo-mpo.gc.ca) is a Research Scientist with Fisheries and Oceans Canada at the Pacific Biological Station in Nanaimo and the Institute of Ocean Sciences in Sidney, BC. His research expertise includes the effects of the environment on finfish and invertebrates; the structure and function of marine ecosystems; ecosystem-based approaches to the management of marine resources; the human dimensions of marine ecosystem changes; and scientific leadership of international and inter-governmental programs on marine ecosystems and global change. Within PICES Ian is a member of the FUTURE Scientific Steering Committee.

Dr. Jennifer Boldt (jennifer.boldt@dfo-mpo.gc.ca) is Research Scientist with Fisheries and Oceans Canada at the Pacific Biological Station in Nanaimo, British Columbia. Her research interests are pelagic forage fish ecology, including responses to biological and environmental drivers, as well as ecosystem indicators and reporting. In PICES, she chairs the MONITOR Committee and is a member of Working Group (WG 36) on Common Ecosystem Reference Points across PICES Member Countries.

Linnea Flostrand (Linnea.Flostrand@dfo-mpo.gc.ca) is a biologist with Fisheries and Oceans Canada at the Pacific Biological Station in Nanaimo, British Columbia. Her responsibilities and research interests support efforts to monitor pelagic ecosystems and forage fish populations with an emphasis on herring, eulachon and sardine.

Moira Galbraith (Moira.Galbraith@dfo-mpo.gc.ca) is an invertebrate taxonomist specializing in zooplankton, on the west coast Canada, in particular. She works at the Institute of Ocean Sciences in Pat Bay, British Columbia.

Dr. Jacquelynne (Jackie) King (Jackie.King@dfo-mpo.gc.ca) is the Program Head of Basin and Coastal-scale Interactions program with Fisheries and Oceans Canada. Her research investigates linkages between coastal-scale ecosystems and basin-scale processes and ecosystems include climate forcing, large-scale oceanographic processes, connectivity in large marine ecosystems and the exchange of energy, between coastal areas and the north Pacific. She collaborates in integrative pelagic field studies along the continental shelf, with her primary focus on understanding the factors controlling the abundance, distribution, and production of salmon and associated species in marine ecosystems. She is also the lead for the Canadian Pacific Shark Research Program; responsible for all Canadian Pacific elasmobranch research and conservation. Within PICES she is Vice-Chair of the Fishery Science Committee, Co-Chair of the Section on Climate Change Effects on Marine Ecosystems, and a member of the FUTURE Scientific Steering Committee.

Jim Murphy (jim.murphy@noaa.gov) is a Fisheries Research Biologist at NOAA's Alaska Fisheries Science Center, and is currently a member of the Salmon Ocean Ecology and Bycatch Assessment team at the Auke Bay Laboratories, in Juneau, Alaska. His research has focused on the marine ecology of Pacific salmon and other pelagic fish species in the northern Bering Sea and Southeast Alaska. Current research includes the application of juvenile abundance to salmon run forecasts models, and life-history classification and diversity in Yukon River Chinook salmon. Jim is a member of the US/Canada Joint Technical Committee of the Yukon River Panel.

Keith Sakuma (keith.sakuma@noaa.gov) is a Research Fisheries Biologist at NOAA Fisheries' Southwest Fisheries Science Center, Fisheries Ecology Division, in Santa Cruz, California. He is the Chief Scientist on the Groundfish Analysis Team's annual Rockfish Recruitment and Ecosystem Assessment Survey, which conducts midwater trawls and CTD casts along the entire coast of California during the spring upwelling season. His research interests include early life history and taxonomy of marine fishes as well as examining the oceanographic factors that affect recruitment strength.

Dr. Andrew Thompson (andrew.thompson@noaa.gov) is a Research Fisheries Biologist at NOAA's Southwest Fisheries Science Center in La Jolla, CA. At present, his research primarily focuses on using larval fish and oceanographic data collected by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program to elucidate causes of dynamics of fish distributions and population sizes in the California Current Ecosystem. He also supervises 3 postdoctoral researchers who are using CalCOFI data to 1) develop Next Generation Sequencing methods to rapidly identify fish species that are present in plankton samples; 2) assess feeding condition of larval anchovy and sardine using bulk and compound-specific stable isotopes and 3) understand if larval condition quantified through otolith characteristics impact rockfish recruitment success. Previously he used field studies, mathematical modelling and genetics to better understand processes affecting the ecology and evolution of mutualistic gobies and shrimps on coral reefs, stream fish in the Appalachian Mountains and southern California, and lizards in the Coachella Valley, California.