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Special Issue: *Transoceanic Dispersal of Marine Life from Japan to North America and the Hawaiian Islands as a Result of the Japanese Earthquake and Tsunami of 2011*

Research Article

The Western Pacific barred knifejaw, *Oplegnathus fasciatus* (Temminck & Schlegel, 1844) (Pisces: Oplegnathidae), arriving with tsunami debris on the Pacific coast of North America

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Abstract

The Western Pacific Ocean barred knifejaw *Oplegnathus fasciatus* was found from 2013 to 2015 along the Pacific Coast of North America from Washington to California. The knifejaw was found in derelict vessels that had arrived on the Pacific Coast and that had been lost during the March 2011 Great Japan Earthquake and Tsunami. Knifejaw were also found free living in the wild in regions known to have received Japanese tsunami marine debris. No previous records of *O. fasciatus* are known east of the Hawaiian Archipelago.

Key words: *Oplegnathus fasciatus*, ocean rafting, marine debris, invasive species, tsunami

Introduction

We report here the first records of the Western Pacific Ocean barred knifejaw (also known as the striped beakfish, the striped knifejaw, and ishidai, イシダイ), *Oplegnathus fasciatus* (Temminck & Schlegel, 1844) in the Northeast Pacific Ocean. The barred knifejaw is a warm-temperate to tropical fish native to Japan, Korea, and China (Sadovy and Cornish 2000; Zongguo and Lin 2001; Nakabo 2002). *Oplegnathus*

Table 1. Northeast Pacific Ocean records of the barred knifejaw *Oplegnathus fasciatus*.

Date	Location (in decimal degrees)	Number and size of Specimens	Remarks and video links
Intercepted inside Japanese Vessels:			
March 22, 2013	**Washington:** Long Beach (46.475511; −124.071969), inside vessel *Sai-shou Maru* [JTMD-BF-40]	5 (up to 15 cm)	4 collected for identification and analysis; 1 live individual relocated to Seaside Aquarium, Seaside, Oregon. video: https://www.youtube.com/watch?v=maACbuRyuGw (accessed November 2017)
April 9, 2015	**Oregon:** between Seal Rock and Ona Beach (44.517033; −124.1203), inside Japanese vessel [JTMD-BF-356]	1	specimen transferred alive to Oregon Coast Aquarium, Newport, Oregon
Discovered in the Wild:			
December 2014 to October 2015	**California:** Monterey Bay: Del Monte Beach (36.653611; −121.915833); San Carlos Beach (37.555555; −122.856388); McAbee Pinnacle (36.630000; −122.097222); South Breakwater wall of Monterey Harbor entrance (37.460000; −122.595277)	at least 2	videos: http://youtu.be/GrHEWl9QYqs (December 2014, filmed by N. Ta; accessed November 2017) and https://www.youtube.com/watch?v=dU4oDbWM6bc (photographed by N. Ta; accessed November 2017) https://vimeo.com/165006145 (October 2015, filmed by A. Kim; accessed November 2017)
February 23, 2015	**Oregon**: in a crab pot along North Beach, between Port Orford and Cape Blanco, just off the Elk River in southern Oregon (42.771944; −124.578333)	1 (13 cm)	Floyd, 2015 video: http://youtu.be/XzA4NPXTYqg (by T. Calvanese; accessed November 2017)

fasciatus has been repeatedly found in the Central North Pacific Ocean as far east as the Hawaiian Archipelago (Randall et al. 1993; Mundy 2005), either as a result of larval dispersal or by rafting with floating seaweed communities or marine debris (Hirosaki 1960; Kojima 1960; Safran and Omori 1990). There are no previous reports of this fish east of the Hawaiian Islands.

Methods

Records of barred knifejaw directly associated with Japanese tsunami marine debris (JTMD) objects (the latter assigned unique numbers, JTMD-BF-, provided herein) were derived from ocean rafting studies commenced in 2012 (Carlton et al. 2017). Records of knifejaws in the wild in Oregon and California were secured by us and with the additional assistance of those listed in the acknowledgements.

Photographs of fish from Washington, Oregon, and California were submitted to Bruce Mundy (National Marine Fisheries Service, Hawai'i, USA), Robert Lea (California Academy of Sciences, San Francisco, California USA; formerly with the California Department of Fish and Wildlife),and Jerry Norton (Pacific Grove, California, USA; formerly with the U.S. National Marine Fisheries Service) for identification and verification. Identification of Monterey Bay individuals was further based on comparison to the native Pacific spadefish *Chaetodipterus zonatus* (Girard, 1858) as detailed below.

Four specimens of barred knifejaw from the vessel *Sai-shou Maru* (whose history is detailed below) were transported to Oregon State University's Hatfield Marine Science Center. Otoliths (sagittae and lapilli) were removed from three individuals (9.2, 10.4 and 12.3 cm standard length, SL) for age determination. One individual was left intact for archival purposes. Otoliths were mounted onto glass slides with thermoplastic resin and polished to reveal daily otolith increments. Daily increment formation has been validated in this species by Wang et al. (2010). Increment analysis was completed using a stereoscope and Image Pro Premier (Media Cybernetics, Rockville MD USA) at 100× to 400× magnification. Lapilli were used for age determination, as they consistently displayed clearer increments then sagittae. Each lapillus was aged at least three times and the average percent error was < 5% (Beamish and Fournier 1981). Due to poor increment clarity in some specimens, the same otolith axis was not aged for all three individuals but increment widths were collected along the axis used for ageing to provide an indication of relative growth. The shorter, dorsal-ventral otolith axis was used for the 10.4 and 12.3 cm SL specimens and the longer, anterior-posterior axis was used for the 9.2 cm SL specimen.

Results

Identification

All specimens of barred knifejaw (Table 1) were less than 15 cm in length at the time they were collected

or observed *in situ*. *O. fasciatus* reaches a maximum length of 80 cm (Masuda et al. 1984); thus, the fish studied here were young. Juvenile barred knifejaw are recognized by an oval and moderately compressed white body with seven vertical black bars. The face is shaded black, featuring a sharp fused-toothed beak surrounded by a thick lip. Spined dorsal fins are short in the front and tallest in the middle; the soft-rayed portions of the dorsal and anal fins are rounded and the caudal fin is slightly rounded or truncate. As barred knifejaws mature, they develop longer bodies and their white color darkens to grey, while the soft dorsal and anal fins become more triangular (Jordan and Fowler 1902; Masuda et al. 1984).

A potential existed for barred knifejaw observed but not collected in Monterey Bay to be mistaken for the native Pacific spadefish *Chaetodipterus zonatus* (Robert Lea, personal communication, 2016). Juvenile *C. zonatus* and *O. fasciatus* both have a round, moderately-compressed profile with an oval shape. However, the arrangement and number of vertical bars differ between *C. zonatus* and *O. fasciatus*, the former having five to six bars with every other bar alternating in length or tapering, while *O. fasciatus* has seven even-length bars from the eye to the base of the caudal fin. Further, juvenile *C. zonatus* have triangular soft dorsal and anal fins, whereas juvenile *O. fasciatus* have round soft dorsal and anal fins (Jordan and Fowler 1902; Miller and Lea 1972; Eschmeyer and Herald 1983). The fish observed in Monterey Bay matched *O. fasciatus.*

Interceptions of barred knifejaws in derelict vessels

Barred knifejaws were found in two vessels arriving in North America that were lost during the tsunami that occurred on March 11, 2011 along the Tohoku coast of Honshu, Japan (Table 1). On March 22, 2013, the small (6.4 m length) fishing vessel *Sai-shou Maru* (斎勝丸, *Dignified Victory*) (JTMD-BF-40) from Rikuzentakata in Iwate Prefecture came ashore in Long Beach, Pacific County, Washington, following a more than 7000 km crossing of the North Pacific Ocean (Figure 1A). The stern of the vessel had been submerged, forming a cavernous habitat in the wet well. The vessel washed ashore upright, trapping five live *O. fasciatus* inside the wet well (Figure 1B, C). One specimen was removed by a local resident and transferred to the Seaside Aquarium (Seaside, Oregon), where it survived until 1 February 2016. The Washington Department of Fish and Wildlife recovered the other four specimens, ranging in size from 9.2 to 12.3 cm, and preserved them for identification and otolith analysis. In addition to the wet well having provided protection from ocean predators, a rich biological community (Figure 1B) may have provided a food source for the fish. More than 50 Japanese species of invertebrates and algae were in the biofouling community aboard the *Sai-shou Maru* (Carlton et al. 2017).

The three fish used for otolith analysis ranged in age from 225 to 232 days (Table 2). The otolith growth of all three individuals declined between 75 to 92 days old, which was between 137 to 150 days prior to landing in Long Beach (Figure 2). The daily otolith increment widths earlier in life (< 90 d) were significantly greater than later (> 90 d) for all three individuals (paired t-tests, $P < 0.001$).

Two years later, on April 9, 2015, the 8 m long bow half of another Japanese fishing vessel (JTMD-BF-356) was found drifting in the ocean 8 km west of Seal Rock, Lincoln County, Oregon. One living knifejaw (approximately 15 cm) and 21 yellowtail jacks (*Seriola aureovittata*) (Craig et al. 2018) were found in the two live tanks inside the vessel. The yellowtail jacks were genetically matched to Western Pacific populations (Craig et al. 2018). This vessel also originated from the Iwate Prefecture, based upon the population genetic structure of the biofouling green alga *Ulva pertusa* collected from the vessel's wave-washed deck (Hanyuda et al. 2017). Also aboard were many other Japanese species, including the barnacle *Megabalanus rosa*, the oyster *Crassostrea gigas,* the isopod *Ianiropsis serricaudis,* and, boring in the wooden gunwales, the shipworm *Lyrodus takanoshimensis.* The knifejaw was transferred along with the jacks to the Oregon Coast Aquarium (OCA), Newport, Oregon.

Discovery of barred knifejaws in the wild

On February 22, 2015 a single knifejaw (13 cm length) was found in a crab pot fished in 27 to 36 meters of water off the coast of southern Oregon between Port Orford and Cape Blanco (Floyd 2015). The fish was captured by a commercial crabber from Port Orford and transported to the Hatfield Marine Science Center for temporary housing and later to the OCA.

Commencing in December 2014, at least two individual knifejaws were observed at multiple sites in Monterey Bay in central California (Table 1), during the following four episodes. All sightings are within 1 km of each other:

1. On December 4, 2014, one specimen was video photographed (by the first author) at a sailboat wreck off of Del Monte Beach (Figures 3, 4).
2. In September 2015, Kim Glenn observed one specimen along the Monterey breakwater at San Carlos Beach; no image was captured but detailed descriptions agree entirely with *O. fasciatus*.

Figure 1. (A) The fishing vessel *Sai-shou Maru*, washed ashore March 22, 2013, in Long Beach, Washington; (B) barred knifejaw *Oplegnathus fasciatus* alive in the vessel wet-well, and (C) being held immediately after capture. Photographs by Travis Haring and Allen Pleus, Washington Department of Fish and Wildlife.

3. In September 2015, Glenn observed one specimen at the McAbee Pinnacle; no image was captured.
4. In September 2015, Andrew Kim observed two individuals at the South Breakwater wall of the Monterey Harbor entrance. One individual did not reappear after the initial observation, but one was video-recorded in October 2015 (Table 1). Mr. Kim observed the *O. fasciatus* on six different dates between September and October 2015. The remaining individual exhibited site faithfulness while weaving in and out of the same wharf pilings

Table 2. Morphometric and growth information for three *O. fasciatus* collected from the vessel *Sai-shou Maru* that landed at Long Beach, Washington, USA. Standard length (SL), mass (grams, g), estimated age (days, d), and mean (± standard deviation) otolith increment width (µm) early (< 90 d old) and later (> 90 d old) in life are included. The decline in growth occurred when the fish were an estimated 75 and 92 d old, which was approximately 137 to 150 d prior to the vessel landing date.

Fish SL (cm)	Mass (g)	Age (d)	Mean (SD) otolith increment width, µm	
			Early	Late
92	23	225	5.1 (1.5)	2.1 (0.4)
104	33	232	2.5 (0.8)	0.8 (0.3)
123	48	229	1.6 (0.3)	1.1 (0.3)

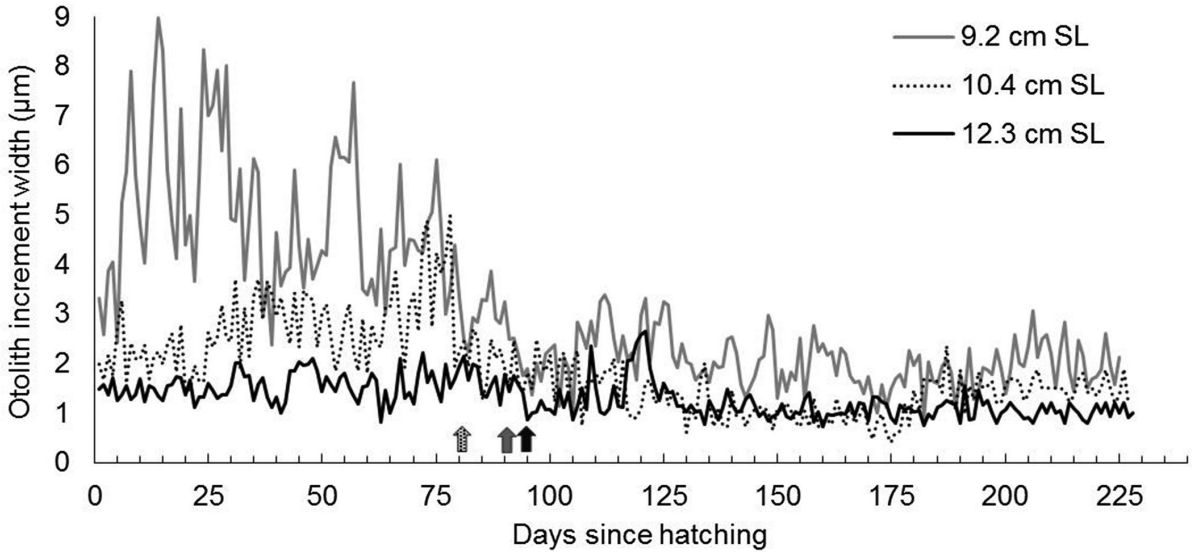

Figure 2. Daily otolith increment width (µm) for three *Oplegnathus fasciatus* that arrived in Long Beach, Washington, USA, inside the vessel *Sai-shou Maru* from Iwate Prefecture, Japan. Note relative declines in growth approximately 137 to 150 days prior to landing, indicated by arrows at day 82 (10.4 cm individual), day 92 (9.2 cm individual), and day 95 (12.3 cm individual). See Table 2 for mean otolith increment widths early and late in life.

Figure 3. A barred knifejaw (center top) swimming with native fish under the bow of the Del Monte sailboat wreck in Monterey Bay, California. Photographed on December 4, 2014 by Nicholas Ta.

throughout this time. It was seen each time schooling with native fishes, and quickly evaded the observer when approached too closely. We conservatively treat the *O. fasciatus* sightings in Monterey Bay as representing two individuals moving between rocky reefs (Figure 5), although more than two fish may have been involved. *O. fasciatus* has not been observed in Monterey Bay since October 2015.

Figure 4. Front and posterior view of an *O. fasciatus* at the Del Monte sailboat wreck. The front view shows the distinctive black beak, and the posterior view shows the fin arrangement. Photographed on December 4, 2014 by Nicholas Ta.

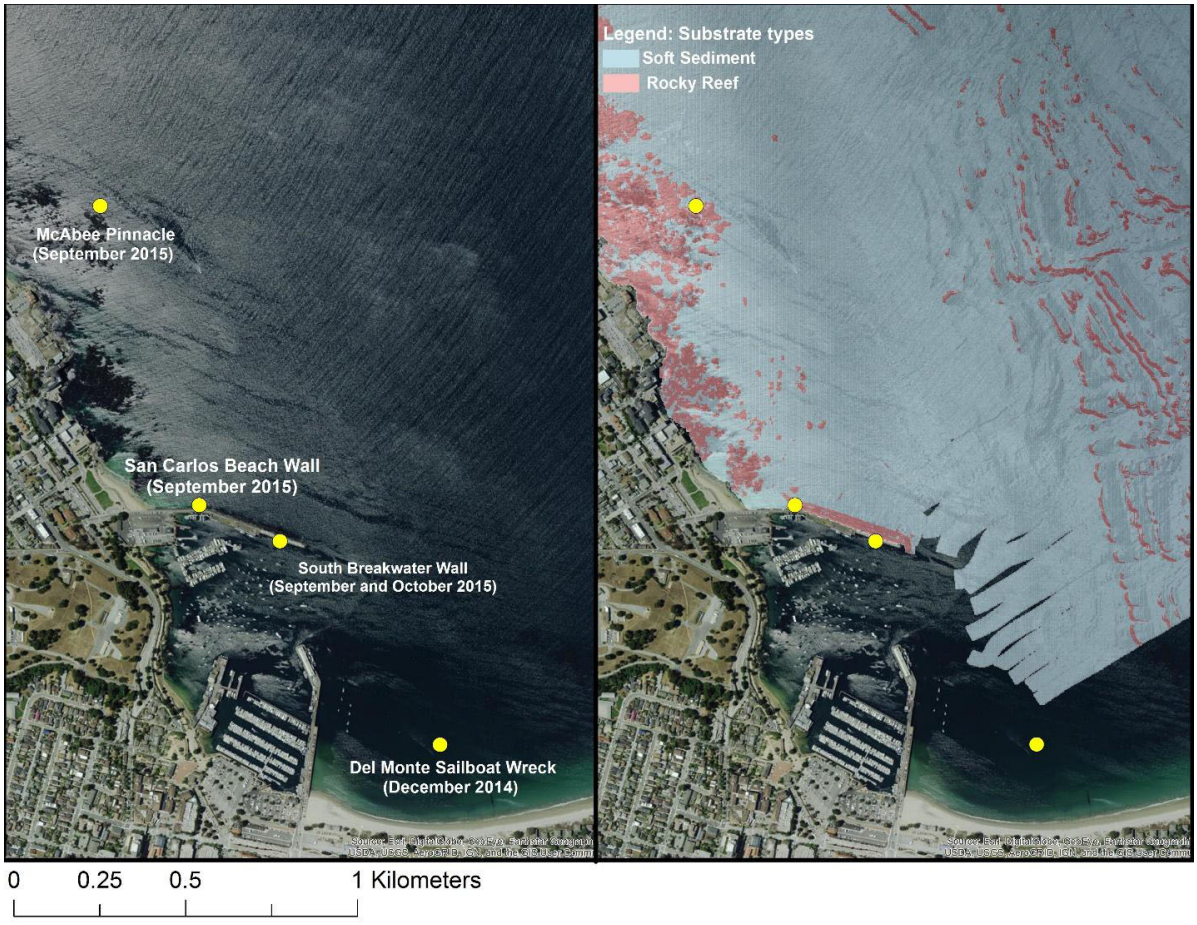

Figure 5. Sites and time line of observations of *Oplegnathus fasciatus* in Monterey Bay, California, with a map showing the composition of the sea floor bottom types.

Discussion

The barred knifejaw *Oplegnathus fasciatus* was not reported from the Pacific coast of North America in more than 150 years of observations (Jordan and Evermann 1898; Eschmeyer and Herald 1983). The appearance of knifejaws in the wild, as we suggest below, is spatially and temporally correlated with the arrival of the Japanese tsunami marine debris field. The debris field departing the Tohoku coast in March 2011 would have passed through the drifting seaweed communities that are common in the Tohoku area and which support a diverse fish assemblage, including *Oplegnathus fasciatus* (Safran and Omori 1990). We explored alternative vector hypotheses as well.

Vectors transporting barred knifejaws to Southern Oregon and California

Relative to the likelihood that *O. fasciatus* discovered in the wild on the Pacific coast arrived with tsunami debris, we note that these collections and observations are coincident in space and time with known debris landings. *O. fasciatus* was discovered in a crab pot in southern Oregon in late February 2015. Between early 2013 and January 2015 in the same region from Cape Arago to Brookings, more than 50 Japanese tsunami marine debris items were recorded to have come ashore, including buoys, pallets, baskets, crates, and post-and-beam Japanese building wood (Carlton et al. 2017); this number is undoubtedly a substantial underestimate of the actual number of arriving items. Southernmost records of knifejaws were in Monterey Bay; in turn, southernmost JTMD landings were also in Monterey Bay. For example, Japanese post-and-beam wood was discovered in March 2015 in Monterey Bay, but likely landed no later than 2014 – concurrent with other arrivals of fresh Japanese lumber landings along the Pacific coast (Carlton et al. 2017).

The estimated ages of the three knifejaws (mean = 228 days) is substantially less than the 742 days between March 11, 2011 and the vessel's landing in North America. We do not know exactly when, where, and how the fish entered the *Sai-shou Maru*, and thus whether the fish were acquired in coastal Japan at some point after March 2011 − depending upon the history and trajectory of the boat − or somewhere en route. The relative decline in otolith increment width that was consistent in the three individuals examined suggests that the vessel moved into cooler or less productive waters during late summer 2012. Movement into cooler water appears to be a more parsimonious explanation, given the abundance of potential temperate-water invertebrate and algal food sources that were transported with the knifejaws, as noted above.

Other potential vectors that may transport knifejaws transoceanically include international shipping (moving living fish in ballast water or in sea chests) as reviewed by Schembri et al. (2010) relative to the appearance of *O. fasciatus* in the Mediterranean (as further discussed below). However, shipping as a vector does not align in time or space with the discovery of knifejaws in California and Oregon. Ballast water management regulations (requiring vessels inbound to U.S. waters from overseas voyages to exchange their water on the high seas) had been in place for a decade prior to the 2014–2015 discovery of knifejaws on the southern Oregon and California coasts (National Research Council 2011). In prior peak eras of massive ballast water release from the 1960s to the 1980s in Oregon and California from Japanese ports, no barred knifejaws were reported or observed on the Pacific coast. Neither region now receives (Port Orford–Cape Blanco) or ever received (Monterey Bay) international shipping from Japan or other regions of the Western Pacific Ocean. While the Port Orford region is only 80 km from the international port of Coos Bay, major shipping in ballast into that Bay from Japan ceased in the 1990s. Finally, we found no evidence for the importation of live knifejaws into the United States for aquaculture, food, or the ornamental aquarium fish trade purposes. Schembri et al. (2010) found the same to be true for the Mediterranean record.

The presence of knifejaws inside derelict Japanese vessels provides support for tsunami debris as a transoceanic dispersal vector for these fish, as does the narrow age range (all juveniles), the juvenile knifejaw's well-known association with drifting material, and their novel appearance on the Pacific coast only after the arrival of tsunami debris commenced.

Knifejaws as potential invasive species and the significance of marine debris as a transoceanic dispersal

The potential for barred knifejaws to colonize distant regions is suggested by their invasion of, and continued presence in, the central Mediterranean Sea. While first detected in 2009 and again several times in 2015, it is not yet known whether knifejaws are reproducing in the Mediterranean (Schembri et al. 2010; Ciriaco and Lipej 2015; Dulcic et al. 2016).

The *O. fasciatus* captured or observed from central California to Washington, are, as with the Mediterranean, likely to be only a fraction of the actual arrivals. The coastal ocean temperatures on the Pacific coast are typically < 12 °C and thus too low for *O. fasciatus*

reproduction, which requires > 22 °C temperatures (Koh and Kim 1992; Tsuchida and Tabata 1996). Nevertheless, barred knifejaws can continue to grow in cold water: the *Sai-shou Maru* fish maintained in an unheated tank of Seaside Aquarium survived for three years and grew from approximately 12 to 22 cm SL, and was becoming darker over time as is common of maturing knifejaws (Keith Chandler and Tiffany Boothe (Seaside Aquarium, Seaside, Oregon, personal communications, 2016). The OCA *O. fasciatus*, which on arrival were of similar sizes as the *Sai-shou Maru* fish, have also grown to 22 cm and 25 cm lengths. And, as noted above, the Monterey Bay fish were actively swimming and foraging around multiple sites.

In summary, the occurrence of knifejaws in the Northeast Pacific Ocean is a striking signal of the potential for anthropogenic debris to be a transoceanic vector. At the same time, these records underscore that the lack of historical observations of knifejaws in the Eastern Pacific suggests that natural rafts of trees, other vegetation, and seaweed rarely survive the passage across the North Pacific Ocean.

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