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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*

Introduction to Special Issue

Ecological and biological studies of ocean rafting: Japanese tsunami marine debris in North America and the Hawaiian Islands

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The potential ecological and biogeographic significance of the Great East Japan Earthquake and Tsunami of March 11, 2011 was initially unforeseen for the Eastern North Pacific Ocean. It was not until June 5, 2012 when possible impacts to the marine biota of North America became evident. Early that morning, beach walkers on the central Oregon coast discovered a massive floating dock densely covered with marine life (Figure 1). The dock was soon identified as having been lost from the fishing port of Misawa in Aomori Prefecture in northeastern Honshu (Table 1 herein; see also Carlton et al. 2017, Figure S1). We designated this dock as Japanese Tsunami Marine Debris Bio-Fouling object number 1 (JTMD-BF-1). The dock was informally named "Misawa 1," after we learned that four identical 20 meter long structures had been lost from this port during the tsunami.

Fortuitously, Misawa 1 landed only 5 km from a marine science research laboratory, the Hatfield Marine

Figure 1. Upper photo, "Misawa 1", a fisheries dock from the Port of Misawa, Aomori Prefecture, washed away March 11, 2011, and landing on Agate Beach, Newport, Oregon, June 5, 2012. Lower left, sea anemones (*Metridium dianthus*) from Japan, along with barnacles (*Semibalanus cariosus*) and mussels (*Mytilus galloprovincialis)* on Misawa 1; lower right, *S. cariosus*, *M. galloprovincialis*, and the barnacle *Megabalanus rosa*. Photographs by Jessica A. Miller.

Science Center (HMSC), in Newport, Oregon. Within a few hours of the dock's discovery, HMSC marine ecologists Jessica Miller, John Chapman, and Gayle Hansen sampled the dock's biofouling community. More than 130 living species of Japanese invertebrates, protists, and algae were collected (Carlton et al. 2017; Hanyuda et al. 2017; G. Hansen, personal communication 2017). These samples represented only a small fraction of the dock's more than 75 square meters of fouling. The 104 species of invertebrates and protists (Table 1) detected aboard, while an underestimate of the total species pool, were to represent fully one-third

Table 1. Examples of some notable Japanese tsunami marine debris (JTMD) objects, relative to patterns of biodiversity and geography.

JTMD-Bio-Fouling (BF) object number, type, origin in Japan if known, and size (in meters)[1] L length H height W width	**Location and date of landing (all in U.S.A.)**[2] WA Washington OR Oregon CA California HI Hawaiian Islands	**Living Japanese fauna** (number of species; from Carlton et al. 2017, except as noted)	**Comments**
BF-1: Fisheries floating dock (Misawa, Aomori Prefecture) 20.1 L, 2.1 H, 5.8 W	OR: Lincoln Co.: Newport: Agate Beach **5 June 2012**	104 (95 invertebrates, 9 protists)[3]	Named "Misawa 1", this was one of four identical docks torn away by the tsunami from the Port of Misawa. It was detected drifting southward past Yaquina Head on the afternoon of June 4, 2012 by Cheryl A. Horton of Oregon State University, and then found ashore to the immediate south on the morning of June 5. On June 5-7, the dock biota, including masses of the kelp *Undaria pinnatifida* (Harvey) Suringar, 1853 and hundreds of thousands of mussels (predominately *Mytilus galloprovincialis*), were scraped off and buried on the high beach. The dock was cut up and removed from the beach July–August 2012. Still alive on the dock on August 3, 2012, inside the seaward bumpers, were the barnacle *Megabalanus rosa* and the mussel *Mytilus galloprovincialis*. In *Science* for October 27, 2017 (vol. 358, no. 6362, page 454), a photograph of a living oyster (*Crassostrea gigas*) and of living barnacles (*M. rosa* and *Semibalanus cariosus*) from BF-1 was published.[4] Sections of Misawa 1 are on outside display at the Hatfield Marine Science Center in Newport, Oregon and on the Newport waterfront.
Fisheries floating dock (Misawa, Aomori Prefecture) 20.1 L, 2.1 H, 5.8 W	HI: drifting past Moloka'i and Maui **17–19 September 2012**	unknown	"Misawa 2" drifted at sea offshore of Maui and Moloka'i; a local vessel fished approximately 2268 kg of mahi-mahi (*Coryphaena hippurus*) from under and around the dock, which had acted as a fish aggregating device. The dock continued west past the Islands; it has not been seen again as of January 2018. No BF number was assigned as this dock was not sampled.
BF-8: Fisheries floating dock (Misawa, Aomori Prefecture) 20.1 L, 2.1 H, 5.8 W	WA: Clallam Co.: Olympic National Park **18 December 2012**	51 (49 invertebrates, 2 protists)	"Misawa 3" was discovered drifting northward on December 14, 2012, 30 km at sea northwest of Grays Harbor WA, by the F/V *Lady Nancy*; it was then found ashore, 100 km north, by a United States Coast Guard helicopter crew on December 18 just south of Mosquito Creek and north of Hoh Head, in the Olympic National Park. A field team sampled the dock on December 21. The marine life on the dock was removed by scraping and bleaching, and by removal of the biofouled fenders, on January 3–4, 2013 (Barnea et al. 2013). The dock was then cut up and removed from the beach in March 2013. "Misawa 4" has not been seen as of January 2018, leaving the fate of that dock and "Misawa 2" (above) unaccounted for.
BF-23: Vessel 9 L	OR: Lincoln Co.: Gleneden Beach **5 February 2013**	53 (50 invertebrates, 3 protists)	One of two vessels (see BF-40, below) that supported the same approximate number of species as on the much larger Misawa 3 (BF-8), above.
BF-40: Vessel *Sai-shou Maru* (Rikuzentakata, Iwate Prefecture) 6.4 L	WA: Pacific Co.: Long Beach Peninsula: Long Beach **22 March 2013**	57 (52 invertebrates, 4 protists, 1 fish)	This vessel came ashore upright (rare for most JTMD boats) with five living Japanese barred knifejaw fish *Oplegnathus fasciatus* (Temminck & Schlegel, 1845) in the stern wet well (Ta et al. 2018). The *Sai-shou Maru* is on display at the Columbia River Maritime Museum, Astoria, Oregon.

Table 1 (continued). Examples of some notable Japanese tsunami marine debris (JTMD) objects, relative to patterns of biodiversity and geography.

JTMD-Bio-Fouling (BF) object number, type, origin in Japan if known, and size (in meters)[1] L length H height W width	**Location and date of landing (all in U.S.A.)**[2] WA Washington OR Oregon CA California HI Hawaiian Islands	**Living Japanese fauna** (number of species; from Carlton et al. 2017, except as noted)	**Comments**
post-and-beam timber (Japanese cedar) 5.5 L	CA: Santa Cruz Co.: Santa Cruz: Three Mile Beach, on the northern shore of Monterey Bay **1 March 2015**	unknown	The farthest south documented JTMD item on the Pacific coast of North America (http://www.santacruzsentinel.com/article/NE/20150303/NEWS/150309922; accessed January 2018). No BF number was assigned, as this construction beam was not sampled.
BF-356: Vessel (name unknown) (Iwate Prefecture) 7. 9 (originally 15.2) L	OR: 8 km offshore (west) of Seal Rock [16 km south of Newport] **9 April 2015**	22 (18 invertebrates, 2 protists, 2 fish)	One of two (the other being BF-40, above) JTMD vessels arriving with living Western Pacific fish (this vessel contained Japanese yellowtail jack *Seriola aureovittata* Temminck & Schlegel, 1845 as well as barred knifejaw *Oplegnathus fasciatus*). While most Japanese vessels are composed largely of plastic and metal, some, such as this vessel, also had wooden components which supported shipworms.
BF-402: Vessel (name unknown) 9 L	WA: Pacific Co: Long Beach Peninsula: Seaview **10 May 2015**	45 (41 invertebrates, 4 protists)	Arriving 4 years and 2 months after the tsunami, this vessel supported the largest diversity of bivalves of any JTMD object. Seventeen living (and an additional 7 dead) bivalve species were aboard, showing a very strong southern species acquisition signature (Carlton et al. 2017). Of the 17 living bivalves, 7 occur only south of the Boso Peninsula; all 7 dead species also occur only south of the Boso Peninsula, suggesting the transit to the Pacific Northwest was not sustainable for many of the warmer water species.
BF-667: Rope and float mass exceeding 15.3 m^3	HI: Kauai: Kapa‘a **7 December 2016**	13 invertebrates (see Comments)	“The very best habitat for invasive species that I recovered [in Hawaii] over (27) years was [this] huge mass of ropes, nets, and more than 120 floats that came ashore in Kapa‘a” in December 2016 (Carl Berg, Surfrider Foundation, Kaua‘i, pers. comm. 16 October 2017). Only a very small area of BF-667 was possible to sample (C. Berg, pers. comm., 2016). A photograph of species from this rope-float mass was on the cover of *Science* for September 29, 2017 (vol. 357, no. 6358).

[1] For growth, reproduction, and structural and elemental (barium/calcium) shell analyses of the mussel *Mytilus galloprovincialis* on BF-1, 8, 23, 40, and other JTMD objects, see Miller et al. (2017).
[2] Latitude and longitude coordinates (in decimal degrees) in Carlton et al. (2017), Supplementary Materials, Table S1.
[3] Total number of species in JTMD-BF-1 (Misawa 1) differs from that (n = 96) shown in Carlton et al. (2017) due to recent updates, including foraminifera (4 additional species, Finger 2018), sponges (2 additional, Elvin et al. 2018), and hydroids (1 additional, Choong et al. 2018). In addition, a metagenomic analysis of BF-1 (see McCuller et al. 2018; Elvin et al. 2018; and Choong et al. 2018) revealed the presence of the Japanese ascidian *Styela clava* (98.4% sequence match over 305b bp to GenBank KC905099 (New Zealand).
[4] For a video of additional species on BF-1, see http://www.sciencemag.org/news/2017/09/japanese-tsunami-transported-hundreds-species-united-states-and-canada-video-reveals. Included in this video are photographs of living barnacles (*Megabalanus rosa*), crabs (*Hemigrapsus sanguineus* and *Oedignathus inermis*) and a sea star (*Asterias amurensis*).

of all the Japanese fauna that was to be documented on JTMD over the next five years.

While Misawa 1 was not the first JTMD object to reach North America, it was the first major arrival available for biological sampling. Several months earlier, in March and April 2012, a 40 meter long Japanese fishing boat, the *Ryou-un Maru* (漁運丸) drifted into the coastal waters of North America (Committee on Commerce, Science, and Transportation 2013). At about the same time other JTMD objects were arriving in Alaska and Canada, including a crated Harley-Davidson motorcycle from

Miyagi Prefecture that came ashore on the British Columbia coast (Billock 2016), and now resides in the Harley-Davidson Museum in Milwaukee, Wisconsin. In contrast, the *Ryou-un Maru* a decommissioned vessel that had been awaiting disposal in Hachinohe, only 20 km south of Misawa, now resides at the bottom of the Pacific Ocean. In retrospect, it was a harbinger of the Misawa 1 dock that would arrive 10 weeks later. Moored in the Port of Hachinohe, the *Ryou-un Maru* may have carried a rich biofouling community into the Northeast Pacific Ocean. Prior to any sampling being feasible, however, the vessel was sunk by the U. S. Coast Guard in more than 1800 meters of water 290 km off the coast of Alaska (https://www.youtube.com/watch?v=C9HW5361bBs; accessed January 2018).

Between June and December 2012, 15 additional objects recognized as JTMD and available for sampling came to our attention (we became aware in 2013 and 2014 of several other JTMD items collected in 2012; Carlton et al. 2017, Table S2). These objects, found in Washington, Oregon, California and the Hawaiian Islands, as well as on Midway, ranged from small buoys to vessels to another of the four Misawa docks (Table 1). Based on this pulse of 2012 arrivals, we established an informal network of private and public personnel from Alaska to California and Hawaii to facilitate timely notice of landings, establish sampling protocols, and secure samples to be sent to our laboratories. Further sampling, processing, analytical, and data archive details are provided in Carlton et al. (2017, and Supplementary materials, Materials and Methods).

Over the next five years, we analyzed samples and photographs from over 600 JTMD objects. These objects were identified as JTMD based upon identification marks, as well as on a broad suite of historical, biological (bioforensic) and biogeographic evidence (see Carlton et al. 2017, Supplementary Materials, Materials and Methods). Underpinning the identification of this *sui generis* debris pulse from the Western to the Eastern Pacific Ocean are the highly constrained temporal nature and geographic origin of this megarafting event, which commenced dramatically in 2012 and was declining by 2017. Coupled with this is the observation that all identified Japanese objects during this period were solely from the tsunami-stricken coast north of Tokyo. If debris had been arriving on a regular basis on Northeast Pacific shores from Japan, independent of the tsunami, before or during this period, rafted objects from a broad region of the Japanese coast would have been observed.

Several examples of notable JTMD objects, relative to patterns of biodiversity and geography, are presented in Table 1. Three of the four Misawa docks were seen (and two acquired) in 2012; the whereabouts of two docks remain unknown. Misawa 3 (BF-8) landed 6 months after Misawa 1 with approximately half the number (49 vs. 95) of invertebrate species, possibly due to increased mortality during the longer sea voyage. In the next 90 days, two vessels (BF-23 and BF-40), both much smaller than Misawa 3, arrived with on-board species diversity rivaling that of Misawa 3, suggesting that these vessels may also have had considerably more species prior to departure from Japan.

One of the most highly publicized vessels (BF-40), and thus better known JTMD arrivals, is the skiff *Sai-shou Maru* (斎勝丸) which rafted across the ocean right side up with living Japanese fish trapped in the boat (Ta et al. 2018). The *Sai-shou Maru* was owned by Katuo Saito of Rikuzentakata City and used for abalone and sea urchin fishing. The Saito family, whose daughter was lost in the tsunami, donated the boat to the Columbia River Maritime Museum in Astoria, Oregon, where it is now on display, with some Japanese barnacles and bryozoans still attached. A second and much larger vessel (BF-356, arriving at half its original size) was discovered drifting offshore off Oregon two years later with additional Japanese fish aboard (Table 1; Craig et al. 2018).

More than four years after the tsunami, one vessel (BF-402), which had rafted from the Tōhoku coast south into tropical waters, arrived in Washington in May 2015 with a remarkable 24 species of coastal bivalves in the fouling community. Seven of the warm-water species on the vessel had succumbed by the time of their arrival in the cold waters of the Pacific Northwest. In December 2016, nearly five years after the tsunami, a mass of rope and buoys (BF-667) from a Japanese oyster farm, and with living species still aboard, landed in Kaua‘i, Hawaii. BF-667 was so large that time and personnel resources permitted only a small sample of the associated biota to be secured.

The sampled objects represent only a small fraction of the debris field and associated Japanese biota that arrived in North America and the Hawaiian Islands. We presume that many millions of objects were washed away from Japan, and that many thousands, if not tens of thousands, of these objects arrived in North America and in Hawaii. One outcome of sampling only a small fraction of the debris is that many JTMD-sourced species arriving on the Pacific coast or in the Hawaiian Islands with the potential to colonize were simply never detected (Carlton et al. 2017). Nevertheless, this research has provided striking insight into the impressive diversity of coastal species susceptible to ocean rafting, and their unexpectedly long survival at sea. This includes several groups of taxa, such as foraminiferans, sponges, hydroids, bryozoans, peracarid crustaceans, and marine insects, that passed through multiple generations. The broad temporal and spatial biological patterns of JTMD are presented in Carlton et al. (2017).

Contributions to the Knowledge of Japanese and North Pacific Ocean Marine Biota

Of particular interest in the study of JTMD was the discovery or resolution of at least 24 species of invertebrates and algae that represent new records for either all of Japan or the Japanese Pacific coast (Table 2). Several of these species were resolved by molecular genetic studies which also supported morphological identifications or contributed additional sequences for selected taxa (Table 3). These new records include the detection of a sponge, *Haliclona xena* de Weerdt, 1986, originally described from The Netherlands and thought to be introduced to Western Europe, but whose provenance was unknown prior to its discovery on JTMD. As noted by Elvin et al. (2018), the determination of this sponge as likely being native to the Northwest Pacific is further in concert with the presence of nearly 30 other species of introduced Japanese invertebrates and algae in The Netherlands.

At least seven new invertebrate and algal species have been detected on JTMD to date, four of which remain undescribed (Table 2). The bryozoan *Bugula tsunamiensis* McCuller, Carlton and Geller, 2018 is one of several new contributions to Japanese bryozoology; along with the recognition of this new *Bugula*, McCuller et al. (2018) elevate another Japanese bryozoan, *Bugula constricta* Yanagi and Okada, 1918, to full species status. Previous studies on the introduced bryozoan *Bugulina stolonifera* (Ryland, 1960) had determined that it had reached Tokyo from southern locations by 2013, but its presence on JTMD from the Aomori Prefecture demonstrates it occurred considerably farther north by 2011. Another bryozoan, *Escharella hozawai* (Okada, 1929), last reported in 1929 when it was first described in Japan, was re-discovered on JTMD (McCuller and Carlton 2018).

As JTMD drifted across the ocean, indigenous high seas species settled on debris items. These included the pelagic gooseneck barnacle *Lepas* spp., the crabs *Planes marinus* Rathbun, 1914 and *P. major* (MacLeay, 1838) and *Plagusia* spp., the polychaete worm *Amphinome rostrata,* the amphipod *Caprella andreae* Mayer, 1890, and the nudibranch *Fiona pinnata* (Eschscholtz, 1831), as well as the oceanic bryozoans *Jellyella tuberculata* (Bosc, 1802), *Jellyella eburnea* (Hincks, 1891), and *Arbopercula angulata* (Levinsen, 1909). Two additional species are now newly added to this neustonic-pleustonic biota. The red alga *Tsunamia transpacifica* West, Hansen, Zuccarello and Hanyuda, 2016 (West et al. 2016) was described from plastic JTMD arriving in Oregon and Washington. Choong et al. (2018) further suggest that the hydroid *Obelia griffini* Calkins, 1899 is a probable member of the North Pacific open ocean community. *Obelia griffini* was long held to be a synonym of the widespread *Obelia dichotoma* (Linnaeus, 1758), no doubt contributing in part to the delay of its recognition as a distinct member of the oceanic biota.

Biological and Ecological Future of Japanese Tsunami Marine Debris Biota

The last documentation of living Japanese invertebrates on JTMD coming ashore in the Central or Eastern North Pacific was between March and May 2017, during a spring pulse, in concert with the patterns noted by Carlton et al. (2017). For example, a JTMD bucket (BF-688) with living mussels (*Mytilus galloprovincialis*) landed on March 2, 2017 on Long Beach, Washington; in the same early March period, a JTMD tray (BF-689) with living Japanese anemones (*Anthopleura* sp.) landed in southern Oregon. A JTMD pulse arrived in Hawaii in April–May 2017, including several objects landing on Kaua‘i with living Japanese anemones (JTMD-BF-691, 702, 705–711) and a JTMD buoy (BF-696) found off the Kona coast on May 11, with a living *M. galloprovincialis*. On April 27, a JTMD buoy (BF-693) landed on Long Beach with living Japanese limpets. Between June 2017 and December 2017, no further living Japanese species have been found on JTMD (including buoys, crates, totes, and vessels) landing in Washington, Oregon, and Hawaii.

Many questions remain about the fate of the JTMD debris field, the endurance of associated species, and the potential for colonization by tsunami-transported species that have arrived in North America and the Hawaiian Islands. While 2011 tsunami marine debris will continue to come ashore in North America and the Hawaiian Islands for a number of years, whether living Japanese species will continue to arrive in 2018 or beyond, having survived for more than seven years in what was long assumed to be a largely in hospitable oceanic environment, remains unknown. And, as Carlton et al. (2017) and Carlton and Fowler (2018) discuss, we also await any detections of establishments of novel species in the Central and Eastern Pacific that may be linked to JTMD ocean rafting transport, even as the debris field steadily fades away.

Table 2. Examples of contributions to the knowledge of the Japanese and North Pacific Ocean marine fauna and flora from studies of Japanese tsunami marine debris (JTMD).

New Records for all of Japan or the Tōhoku Coast of Honshu				
Taxon		**Previously known from**	**Comments**	**Reference**
Porifera (sponges)	*Haliclona xena* de Weerdt, 1986	Eastern North Atlantic Ocean	regarded as introduced to Western Europe; possible endemic region unknown until now	Elvin et al. 2018
	Halisarca "*dujardini*" Johnston, 1842	Peter the Great Bay		
Hydrozoa (hydroids)	*Plumalecium plumularioides* (Clark, 1877)	Kurile Islands and Bering Sea	placed in a new family, Plumaleciidae Choong and Calder, 2018 in Choong et al. 2018	Choong et al. 2018
	Hydrodendron gracile (Fraser, 1914)	Kurile Islands and Sea of Japan		Calder et al. 2014
Polyplacophora (chitons)	*Acanthochitona rubrolineata* (Lischke, 1873)	Southern Hokkaido to China	a former synonym of *A. achates*, revived as a valid species	Eernisse et al. 2018
Ostracoda	*Sclerochilus verecundus* Schornikov, 1981	Shikotan Island to South Korea	may have been mis-identified previously from the Tōhoku region as *Sclerochilus mukaishimensis* Okubo, 1977	Tanaka et al. 2018
Copepoda	*Harpacticus nicaeensis* Claus, 1866-group	Mediterranean and Ponto-Caspian Basin	may be an undescribed species	Cordell 2018
Bryozoa	*Biflustra* cf. *arborescens* (Canu and Bassler, 1928)	Western and Eastern Atlantic Ocean	may also have been acquired south of Tōhoku coast	McCuller and Carlton 2018
	Conopeum nakanosum Grischenko, Dick and Mawatari, 2007	South China Sea; introduced to New Zealand-Australia and Brazil		
	Cribrilina mutabilis Ito, Onishi and Dick, 2015	Hokkaido		
	Microporella luellae Grischenko, Dick and Mawatari, 2007	Hokkaido		
	Microporella neocriboides Dick and Ross, 1988	Hokkaido and Alaska		
	Watersipora mawatarii Vieira, Spencer Jones and Taylor, 2014	Hokkaido	may also have been acquired south of Tōhoku coast	
	Callopora craticula (Alder, 1856)	Hokkaido		
	Bugulina stolonifera (Ryland, 1960)	Tokyo Bay	northward extension to Tokyo Bay to 2013 (McCuller and Carlton 2018), but present by 2011 in Misawa (Aomori Prefecture)	
New Records for Central Honshu				
Bryozoa	*Bugula constricta* Yanagi and Okada, 1918	Sagami Bay	Elevated to full species status from *Bugula scaphoides constricta*	McCuller et al. 2018
New Species				
Taxon		**Comments**		**Reference**
Polyplacophora (chitons)	*Acanthochitona* n.sp.	Honshu and Ogasawara (Bonin) Islands		Eernisse et al. 2018
Ostracoda	*Sclerochilus* n. sp.			Tanaka et al. 2018
Bryozoa	*Bugula tsunamiensis*			McCuller et al. 2018
	Callaetea n. sp.			McCuller and Carlton 2018
	Arbocuspis n. sp.			
Rhodophyta (red algae)	*Tsunamia transpacifica*	new genus and new species		West et al. 2016
	Stylonematophyceae, n. sp.	known as a DNA sequence		
Rediscovered Species on Tōhoku Coast of Honshu				
Taxon		**History**		**Reference**
Bryozoa	*Escharella hozawai* (Okada, 1929)	Last collected in 1920s in Mutsu Bay, Aomori Prefecture		McCuller and Carlton 2018
Recognition of Novel Member of Oceanic Fauna				
Hydrozoa (hydroids)	*Obelia griffini* Calkins, 1899	Previously considered as a member of the neritic fauna		Choong et al. 2018

Table 3. Examples of molecular genetic contributions to Japanese tsunami marine debris (JTMD) invertebrate and fish biodiversity (* detected in JTMD only as a DNA sequence).

Taxon		JTMD sequence match (98% or better) to GenBank sequence from:	JTMD sequences (GenBank deposition numbers)	Reference
Porifera (sponges)	**Halisarca "dujardini"*	White Sea (EU237483) and North Sea (HQ606143)	MG808392	Elvin et al. 2018
	**Haliclona xena*	The Netherlands (JN242209)	MG808391	Elvin et al. 2018
Hydrozoa (hydroid)	**Gonionemus vertens*	Japan, Russia, New England (numerous sequences)		Choong et al. 2018
	Eutima japonica	Japan (AB458489)		Calder et al. 2014
Bryozoa	**Bugulina stolonifera*	Galizia, Spain (KC129849-1)		McCuller and Carlton 2018
	Bugula tsunamiensis, new species	—	MF593127	McCuller, Carlton and Geller 2018
Bivalvia: Teredinidae (shipworms)	*Bankia bipennata*	—	KY250360	Treneman et al. 2018a, b
	Bankia carinata	—	KY250355	
	Psiloteredo sp.	—	KY250324-29; KY250343-49	
	Teredothyra smithi	—	KY250357-59	
Polyplacophora (chitons)	*Mopalia seta*	Russia (EU407017, EU409069)	MG680054-58 MG680083-86	Eernisse et al. 2018
	Acanthochitona achates	—	MG677923-34 MG679991-6780001	
	Acanthochitona sp. A	—	MG79937-53 MG80003-80020	
	Acanthochitona rubrolineata	—	MG679935-36 MG680002	
Pisces: Carangidae (yellowtail jack)	*Seriola aureovittata*	Japan (numerous sequences)	MF069448–MF069455 MF0609456–MF069462	Craig et al. 2018

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References

Barnea N, Antrim L, Lott D, Galasso G, Suess T, Fradkin S (2013) The response to the Misawa dock on the Washington coast. NOAA Office of Response and Restoration, Marine Debris Program, 25 pp. https://marinedebris.noaa.gov/report/response-misawa-dock-washington-coast

Billock J (2016) The motorcycle that rode the tsunami. Smithsonian Magazine.com. https://www.smithsonianmag.com/travel/motorcycle-rode-tsunami-180960327/ (accessed January 2018)

Calder DR, Choong HHC, Carlton JT, Chapman JWC, Miller JA, Geller J (2014) Hydroids (Cnidaria: Hydrozoa) from Japanese tsunami marine debris washing ashore in the northwestern United States. *Aquatic Invasions* 9: 425–440, https://doi.org/10.3391/ai.2014.9.4.02

Carlton JT, Chapman JWC, Geller JB, Miller JA, Carlton DA, McCuller MI, Treneman NC, Steves BP, Ruiz GM (2017) Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography. *Science* 357: 1402–1406, https://doi.org/10.1126/science.aao1498

Carlton JT, Fowler AE (2018) Ocean Rafting and Marine Debris: A Broader Vector Menu Requires a Greater Appetite for Invasion Biology Research Support. *Aquatic Invasions* 13: 11–15, https://doi.org/10.3391/ai.2018.13.1.02

Choong HHC, Calder DR, Chapman JWC, Miller JA, Geller JB, Carlton JT (2018) Hydroids (Cnidaria: Hydrozoa: Leptothecata and Limnomedusae) on 2011 Japanese tsunami marine debris landing in North America and Hawai‘i, with revisory notes on *Hydrodendron* Hincks, 1874 and a diagnosis of Plumaleciidae, new family. *Aquatic Invasions* 13: 43–70, https://doi.org/10.3391/ai.2018.13.1.05

Committee on Commerce, Science, and Transportation (2013) Stemming the Tide: The U.S. Response to Tsunami Generated Marine Debris: Hearing Before the Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard of the Committee on Commerce, Science, and Transportation, United States Senate, One Hundred Twelfth Congress, Second Session, May 17, 2012. Senate Hearing 112–757. U. S. Government Printing Office, Washington, D.C.

Cordell JR (2018) Harpacticoid copepods associated with Japanese tsunami debris along the Pacific coast of North America. *Aquatic Invasions* 13: 113–124, https://doi.org/10.3391/ai.2018.13.1.09

Craig MT, Burke J, Clifford K, Mochon-Collura E, Chapman JWC, Hyde JR (2018) Trans-Pacific rafting in tsunami associated debris by the Japanese yellowtail jack, *Seriola aureovittata* Temminck & Schlegel, 1845 (Pisces, Carangidae). *Aquatic Invasions* 13: 173–177, https://doi.org/10.3391/ai.2018.13.1.13

Elvin DW, Carlton JT, Geller JB, Chapman JW, Miller JA (2018) Porifera (Sponges) from Japanese Tsunami Marine Debris arriving in the Hawaiian Islands and on the Pacific coast of North America. *Aquatic Invasions* 13: 31–41, https://doi.org/10.3391/ai.2018.13.1.04

Eernisse DJ, Draeger A, Pilgrim EM (2018) Chitons (Mollusca: Polyplacophora) rafted on tsunami debris from Japan to the shores of Washington, Oregon, and Hawaii. *Aquatic Invasions* 13: 71–86, https://doi.org/10.3391/ai.2018.13.1.06

Finger KL (2018) Tsunami-generated rafting of foraminifera across the North Pacific Ocean. *Aquatic Invasions* 13: 17–30, https://doi.org/10.3391/ai.2018.13.1.03

Hanyuda T, Hansen GI, Kawai H (2017) Genetic identification of macroalgal species on Japanese tsunami marine debris and genetic comparisons with their wild populations. *Marine Pollution Bulletin*, https://doi.org/10.1016/j.marpolbul.2017.06.053

McCuller MI, Carlton JT (2018) Transoceanic rafting of Bryozoa (Cyclostomata, Cheilostomata, and Ctenostomata) across the North Pacific Ocean on Japanese tsunami marine debris. *Aquatic Invasions* 13: 137–162, https://doi.org/10.3391/ai.2018.13.1.11

McCuller MI, Carlton JT, Geller JB (2018) *Bugula tsunamiensis* n. sp. (Bryozoa, Cheilostomata, Bugulidae) from Japanese tsunami marine debris landed in the Hawaiian Archipelago and the Pacific coast of the USA. *Aquatic Invasions* 13: 163–171, https://doi.org/10.3391/ai.2018.13.1.12

Miller JA, Carlton JT, Chapman JW, Geller JB, Ruiz GM (2017) Transoceanic dispersal of the mussel *Mytilus galloprovincialis* on Japanese tsunami marine debris: An approach for evaluating rafting of a coastal species at sea. *Marine Pollution Bulletin*, https://doi.org/10.1016/j.marpolbul.2017.10.040

Ta N, Miller JA, Chapman JW, Pleus AE, Calvanese T, Miller-Morgan T, Burke J, Carlton JT (2018) The Western Pacific barred knifejaw, *Oplegnathus fasciatus* (Temminck & Schlegel, 1844) (Pisces: Oplegnathidae); arriving with tsunami debris on the Pacific coast of North America. *Aquatic Invasions* 13: 179–186, https://doi.org/10.3391/ai.2018.13.1.14

Tanaka H, Yasuhara M, Carlton JT (2018) Transoceanic transport of living marine Ostracoda (Crustacea) on tsunami debris from the 2011 Great East Japan Earthquake. *Aquatic Invasions* 13: 125–135, https://doi.org/10.3391/ai.2018.13.1.10

Treneman NC, Borges LMS, Shipway JR, Raupach MJ, Altermark B, Carlton JT (2018a) A molecular phylogeny of wood-borers (Teredinidae) from Japanese tsunami marine debris. *Aquatic Invasions* 13: 101–112, https://doi.org/10.3391/ai.2018.13.1.08

Treneman NC, Carlton JT, Borges LMS, Shipway JR, Raupach MJ, Altermark B (2018b) Species diversity and abundance of shipworms (Mollusca: Bivalvia: Teredinidae) in woody marine debris generated by the Great East Japan Earthquake and Tsunami of 2011. *Aquatic Invasions* 13: 87–100, https://doi.org/10.3391/ai.2018.13.1.07

West JA, Hansen GI, Hanyuda T, Zuccarello GC (2016) Flora of drift plastics: a new red algal genus, *Tsunamia transpacifica* (Stylonematophyceae) from Japanese tsunami debris in the northeast Pacific Ocean. *Algae* 31: 289–301, https://doi.org/10.4490/algae.2016.31.10.20