Megarafting: The Role of Marine Debris in the Transoceanic Transport of Marine Life

Sixth International Marine Debris Conference
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NSF PICES 環境省 Ministry of the Environment Sea Grant Oregon

The Great East Japan Earthquake
東日本大震災
March 11, 2011: Wave Heights

Wave height estimated at 40.5 m (133 feet) in Miyako

Objects Washed Out to Sea …….

Household **goods and possessions**

Homes and businesses, including **post and beam** building wood characteristic of Japanese construction

Vast amounts of **fisheries, fishing, and aquaculture gear**

Large **ships**

Over 1,000 small and medium-sized **vessels**

Coastal **forests**

Small **piers**, **pontoons**, and large **docks**

These Items Either ….

- **Sank down to the seabed**
- **Were carried back to shore**
- **Went to sea**

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- **Sank down to the seabed**
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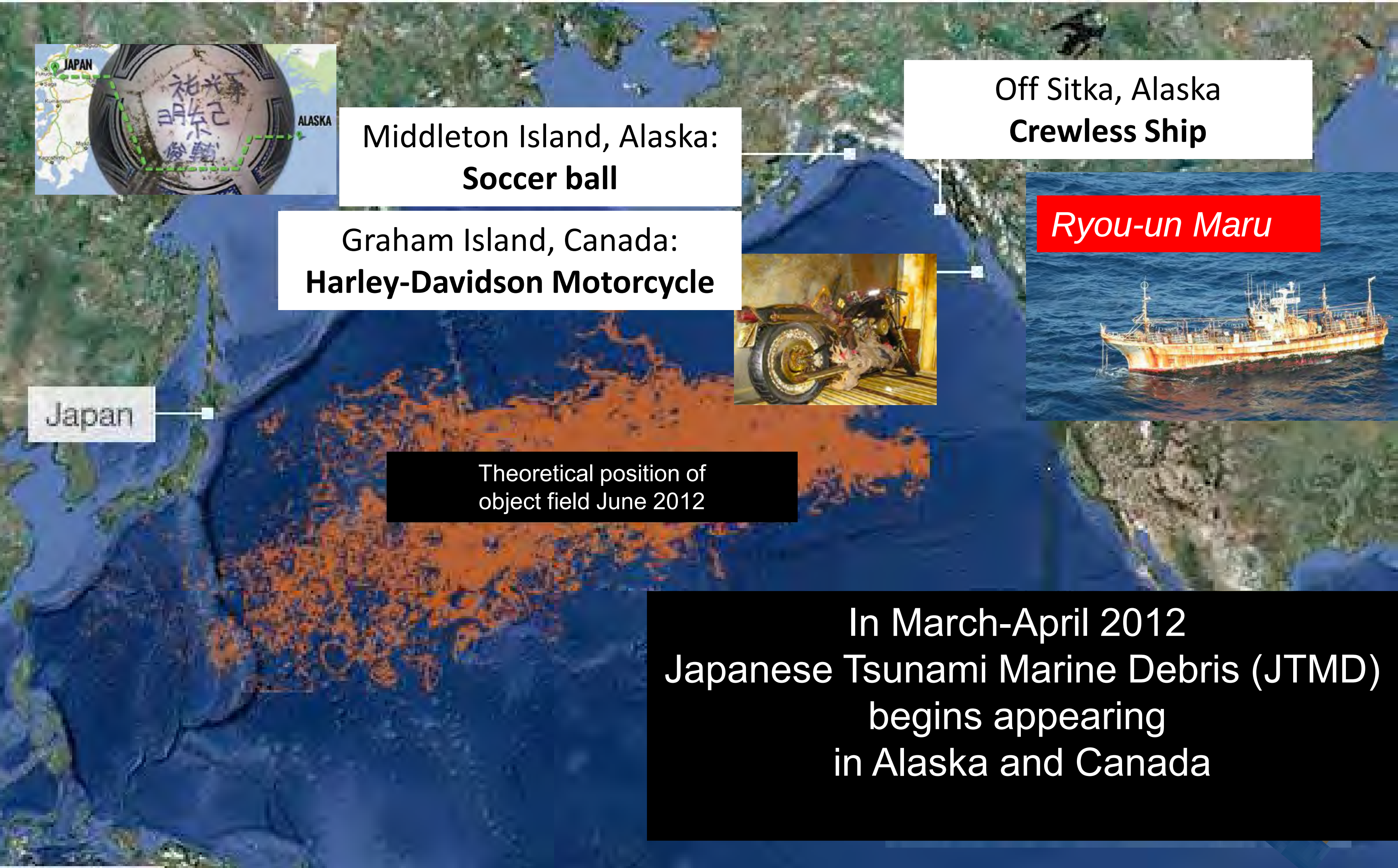
What ensued over the next 6 years became the
first opportunity in the history of marine science
to track a large-scale **(7000 km+)**
transoceanic rafting event of marine life,

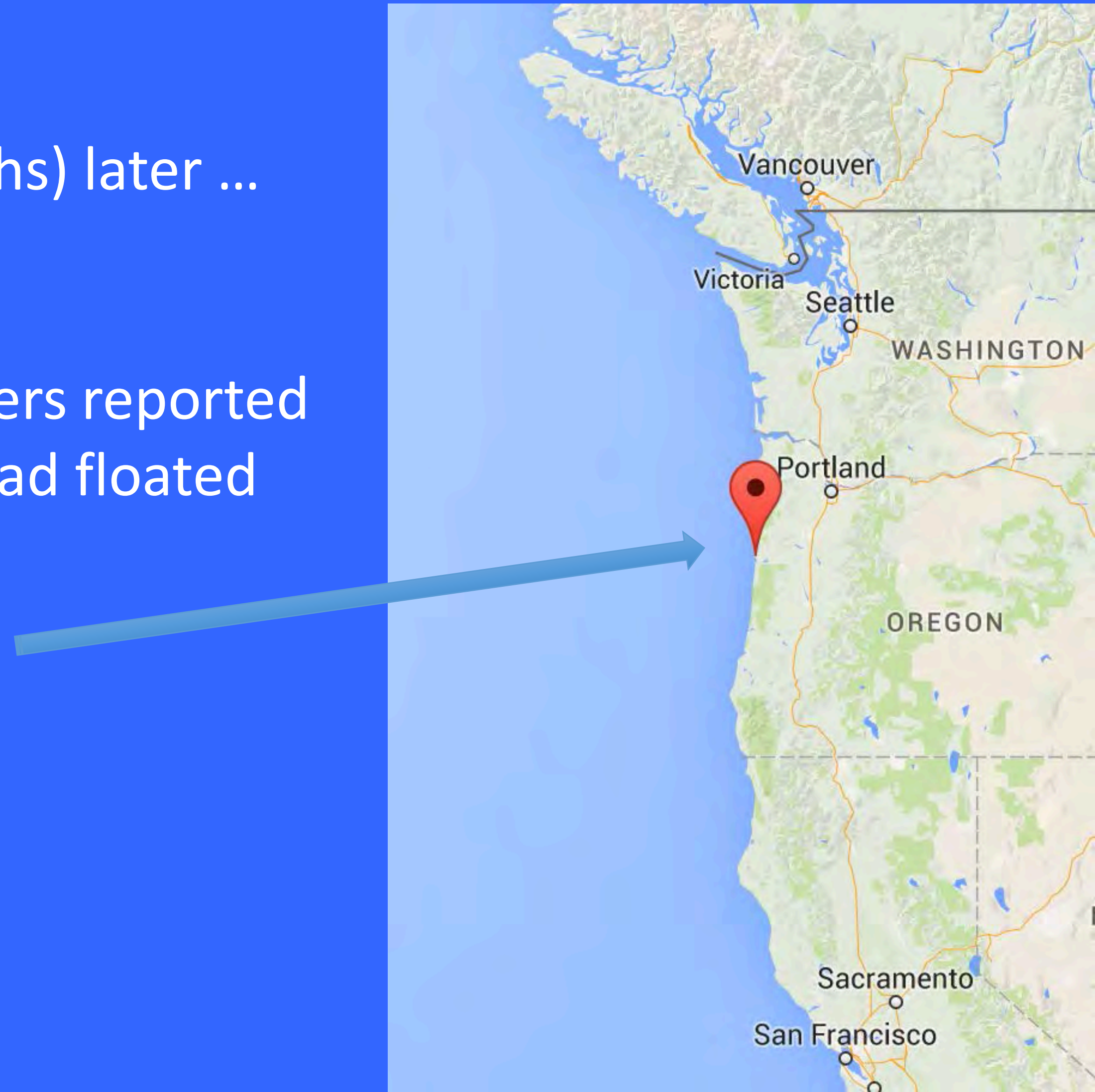
- on a **vast amount of floating debris**
- from an exact **known origin**
- with an exact **known sea-entry time**
- over **multiple years**



JAPAN
ALASKA
Middleton Island, Alaska:
Soccer ball
Graham Island, Canada:
Harley-Davidson Motorcycle
Off Sitka, Alaska
Crewless Ship
Ryou-un Maru
Japan
Theoretical position of
object field June 2012
In March-April 2012
Japanese Tsunami Marine Debris (JTMD)
begins appearing
in Alaska and Canada

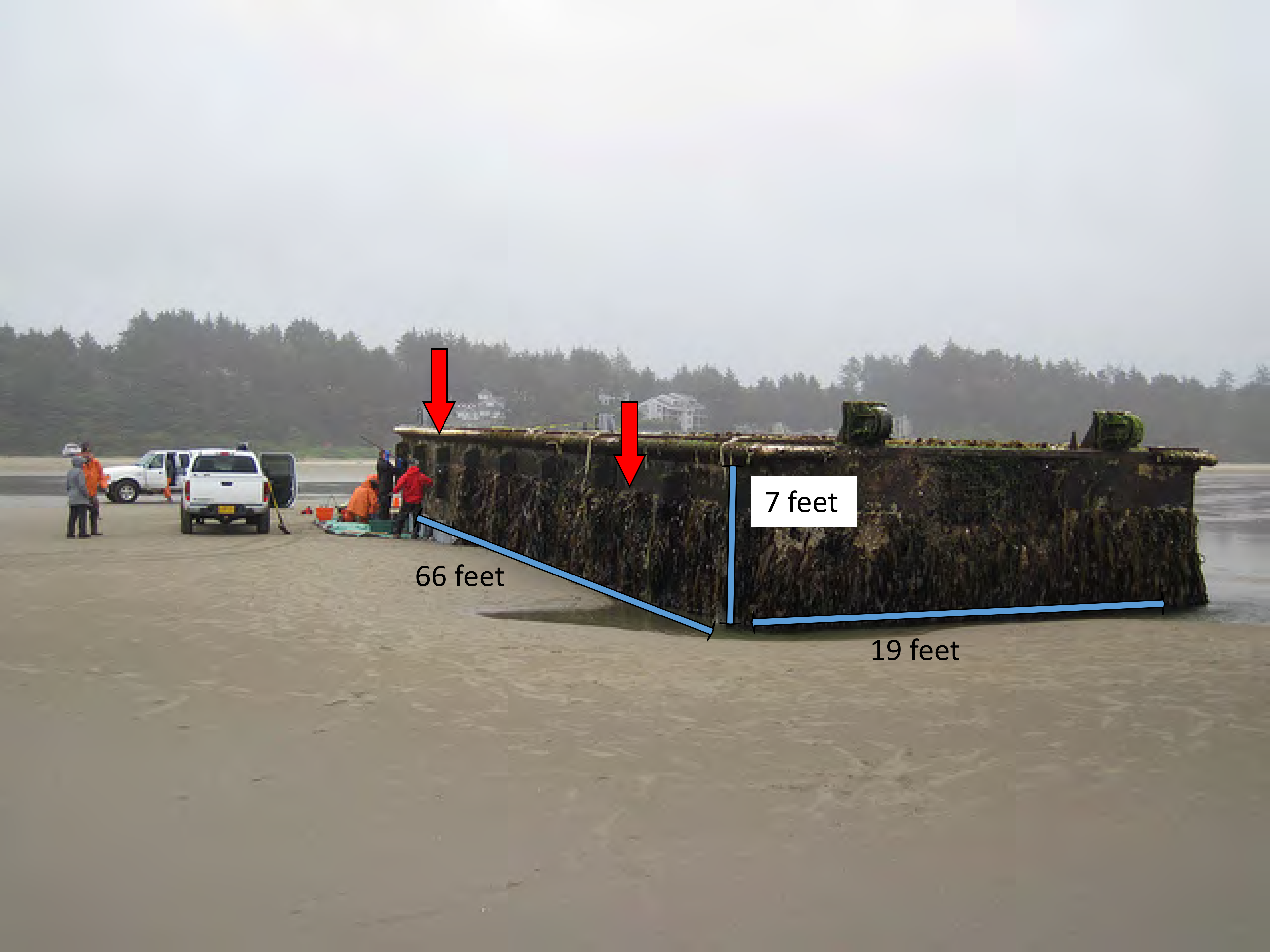
And then…

- On the morning of Tuesday, June 5, 2012
- 451 days (14.5 months) later …
- Morning beach walkers reported that a “large dock” had floated ashore just north of Newport, Oregon



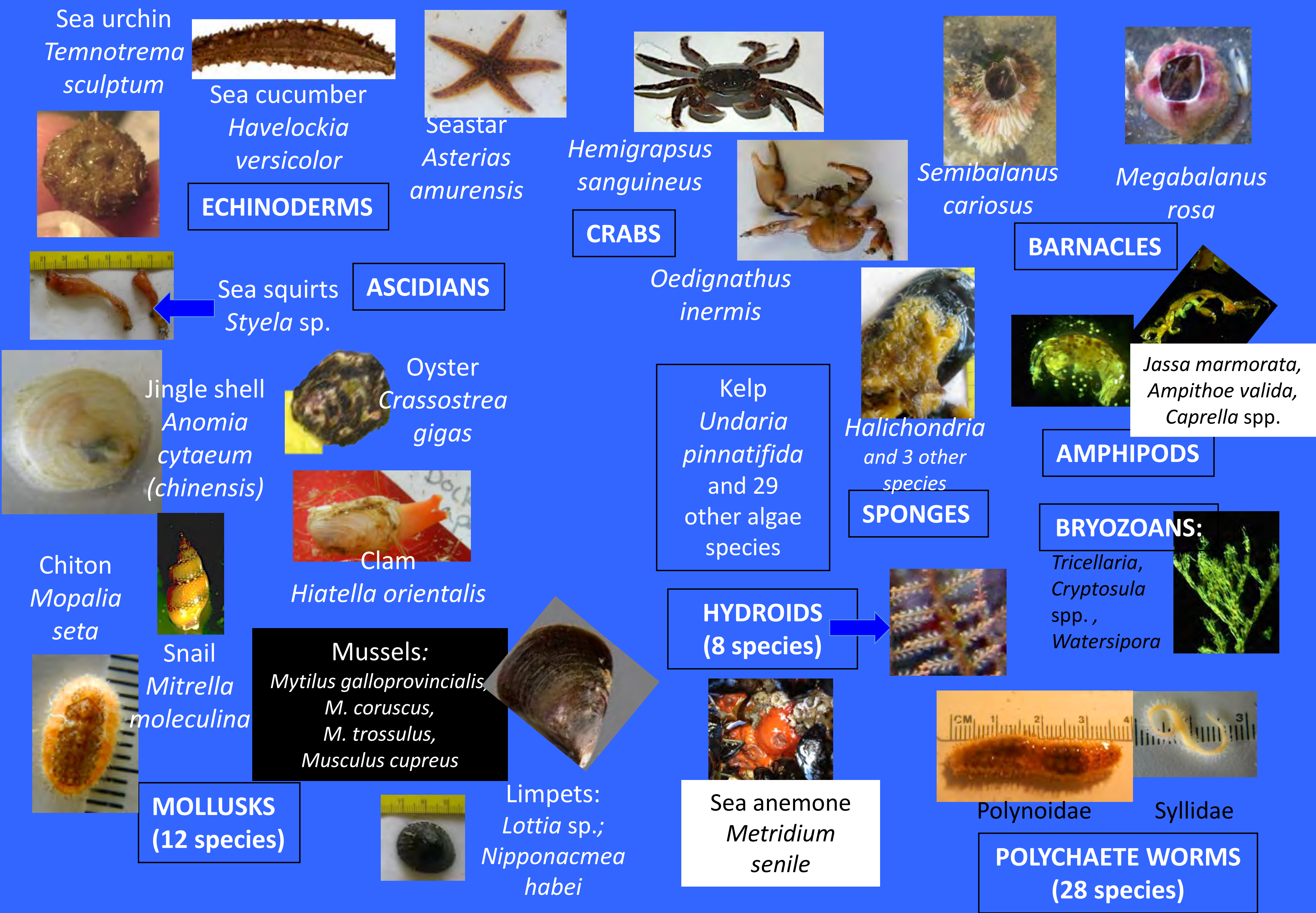

7,000 km journey
across the
Pacific Ocean


Port of Misawa,
built 2008
AP

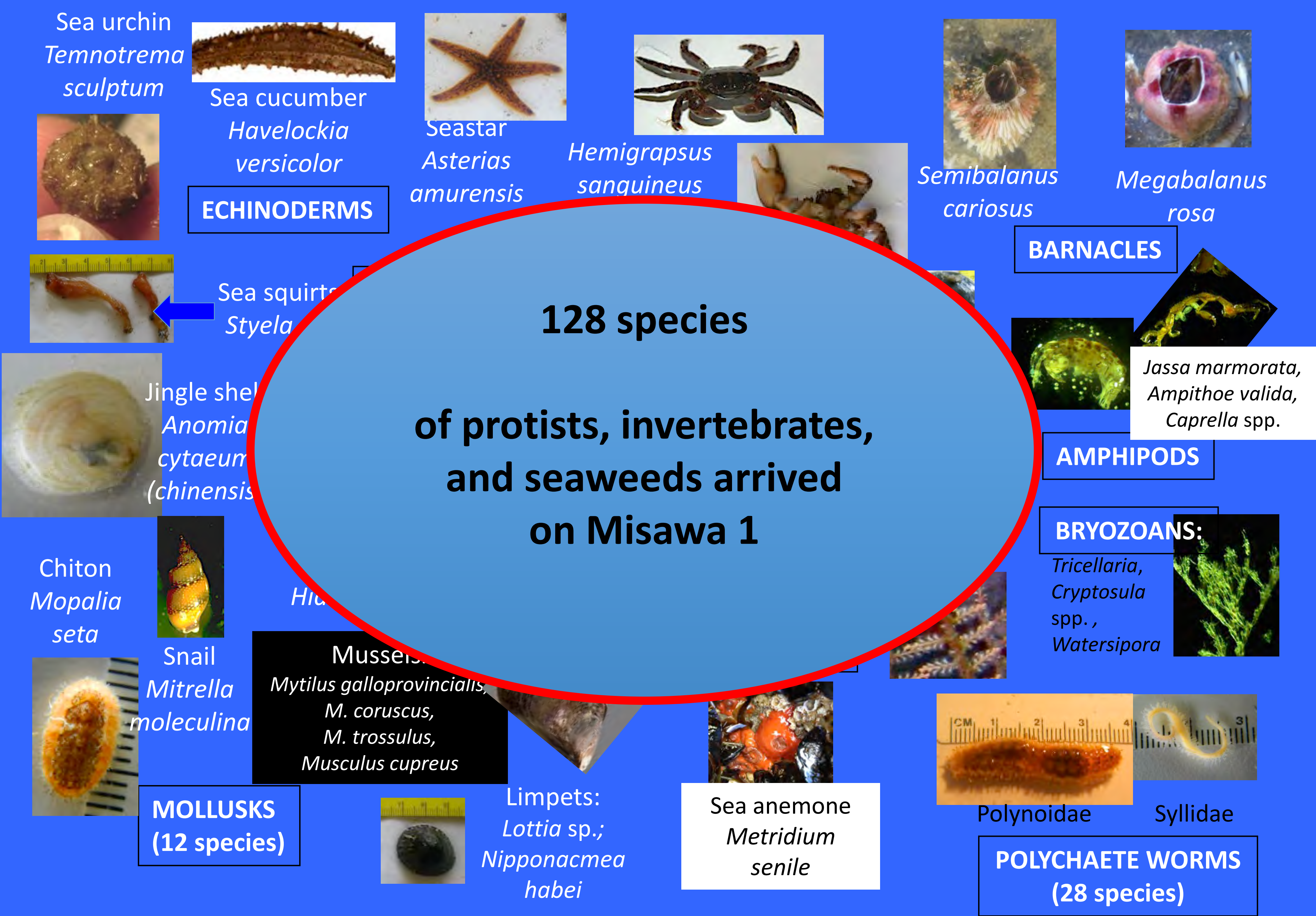

7 feet
66 feet
19 feet

Mediterranean mussel
Mytilus galloprovincialis:
A well-known invasive species
Japanese kelp (seaweed, algae)
Undaria pinnatifida:
A well-known invasive species

Examples of coastal organisms on "Misawa 1": Landed Agate Beach, Oregon, June 5, 2012



Examples of coastal organisms on "Misawa 1": Landed Agate Beach, Oregon, June 5, 2012



Over the ensuing months, many objects began to come ashore on the Pacific coast and in the Hawaiian Islands ….

Sample acquisition: Since 2012

* **Established extensive network** of local, state, provincial, and federal officials, private citizens, environmental groups, in Alaska, British Columbia, Washington, Oregon, California, and Hawaii

* **Established protocols** – as best as possible, feasible, and practical – for real-time communication, notification, collections, photography

* **Preserved biological samples** sent to laboratories at Williams-Mystic (Carlton), Oregon State University (Miller/Chapman), Moss Landing (Geller) and Smithsonian (Ruiz)

How do we know that a given object was lost in Japan on March 11, 2011?

A combination of evidence:

Formal identification

Registration numbers or other identification, and then traced by Consulate to the tsunami

Known Japanese manufactory / origin

Unique Japanese construction (buoys, lumber)

Bioforensics: source region biohomogeneity fingerprint

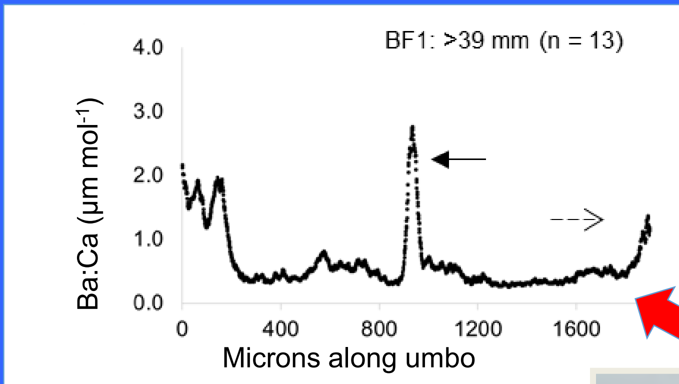
Biota typical of Honshu tsunami epicenter

Pulse event timing

A *sui* generis debris pulse from the Western Pacific

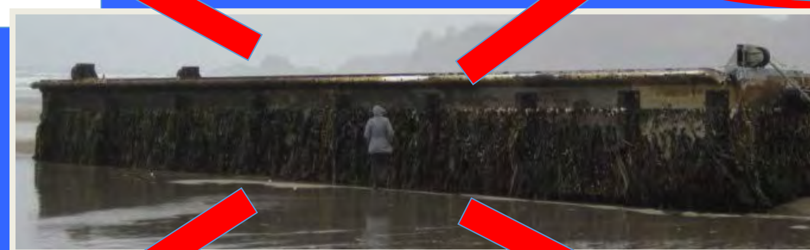
Examples of Sample Analyses

Chemical & Growth History: Mussels

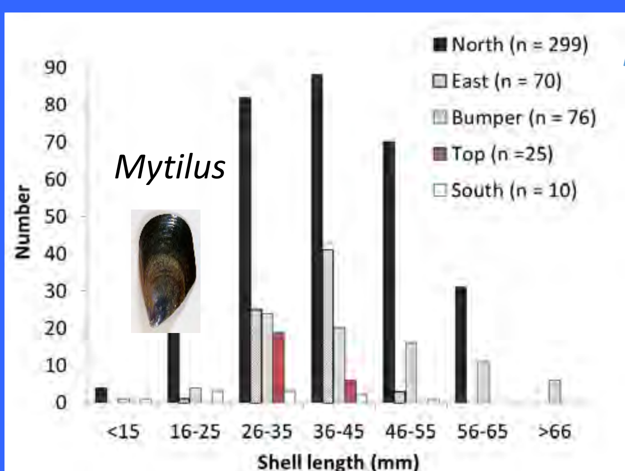


Biodiversity Assessment

More than 80 taxonomists assisting in species identifications



Population Characteristics: Mussels and Arthropods



Genetic Barcoding and Metagenomics

% Pairwise Id	Bit-Score	Description	E Value	Grade	Name
100.00%	1221.76	Mytilus galloprovincialis voucher LSGB41	0	96.40%	GQ480281
100.00%	800.72	Haliclona xena voucher HAP244 cytochrc	0	92.90%	JN242209
100.00%	499.716	Semibalanus cariosus clone COR1_CO1 c	1.10E-140	95.60%	GQ902241
100.00%	547.729	Semibalanus cariosus isolate HMS267 cy	4.20E-155	96.30%	GU442642
100.00%	507.102	Semibalanus cariosus isolate HMS267 cy	6.59E-143	96.00%	GU442642
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100.00%	510.796	Semibalanus cariosus isolate HMS267 cy	5.13E-144	96.00%	GU442642
100.00%	503.409	Halichondria panicea cytochrome oxidas	8.62E-142	95.20%	KC869423
100.00%	484.943	Jassa marmorata isolate M123-01 cytoch	2.97E-136	95.60%	EU243666

Japanese Tsunami Marine Debris (JTMD):

We analyzed

634 objects

(from a field of 1000s to 10s of 1000s of biofouled objects)

(docks, boats, floats, buoys, post-and-beam wood, *et al.*)

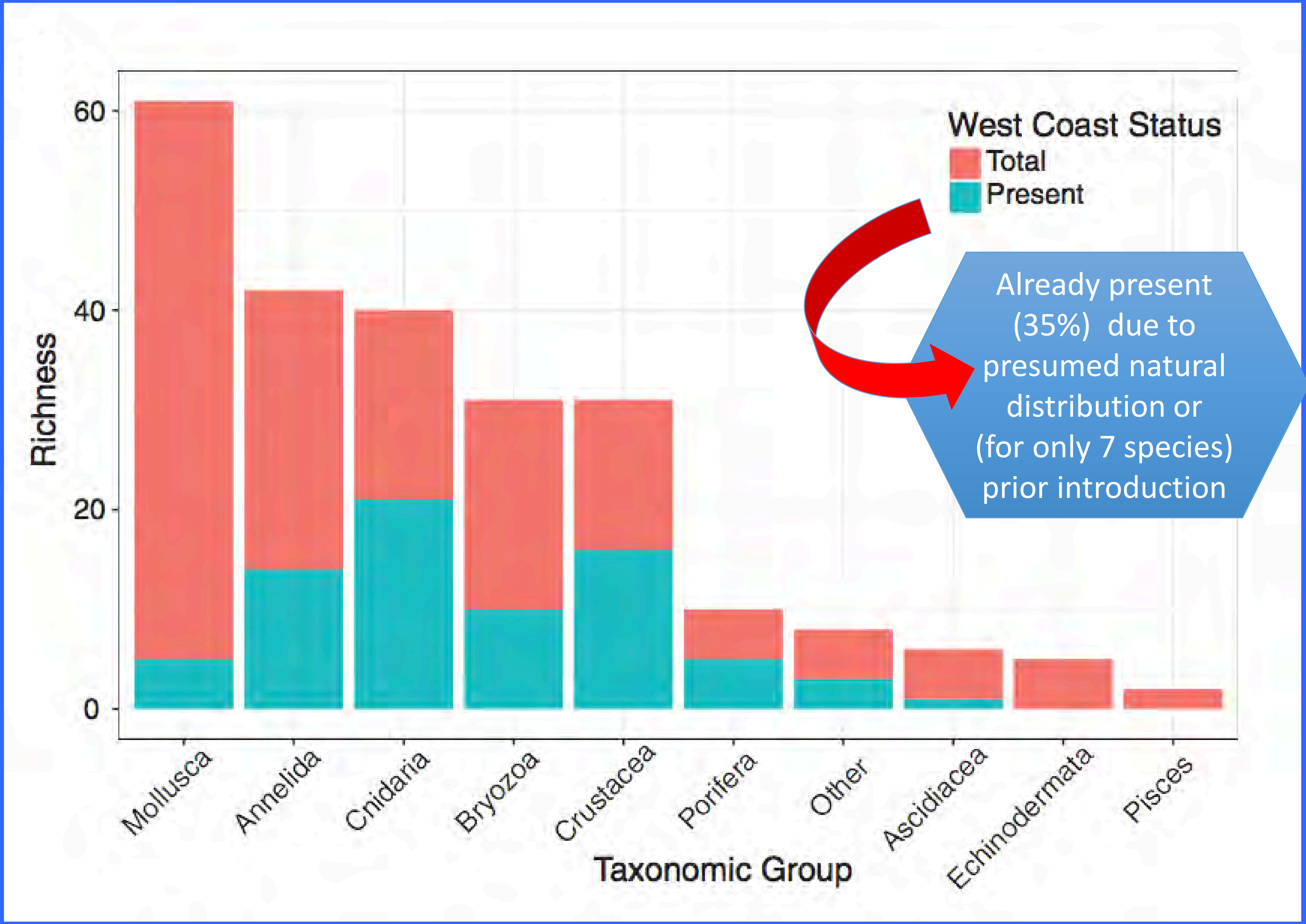
landing in AK, BC, WA, OR, CA, and HI

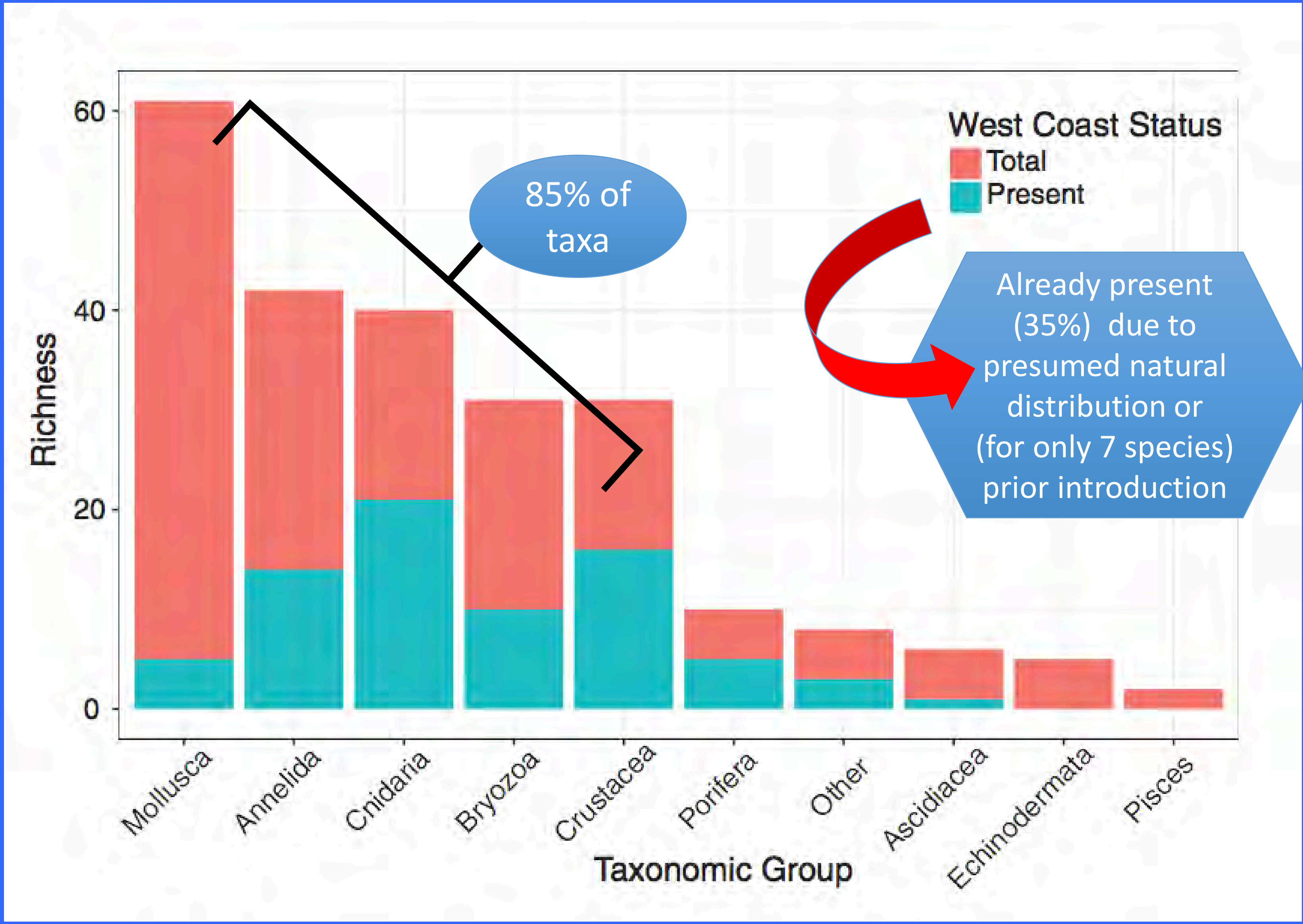
generated by the 2011 Tohoku Tsunami
and with
Japanese species aboard

JTMD Diversity

372 Japanese species:

Invertebrates	290
Fish	2
Algae	80


West Coast Status
Total
Present
Already present (35%) due to presumed natural distribution or (for only 7 species) prior introduction
Richness
60
40
20
0
Mollusca
Annelida
Cnidaria
Bryozoa
Crustacea
Porifera
Other
Ascidiacea
Echinodermata
Pisces
Taxonomic Group



West Coast Status
Total
Present
85% of taxa
Already present (35%) due to presumed natural distribution or (for only 7 species) prior introduction
Richness
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Annelida
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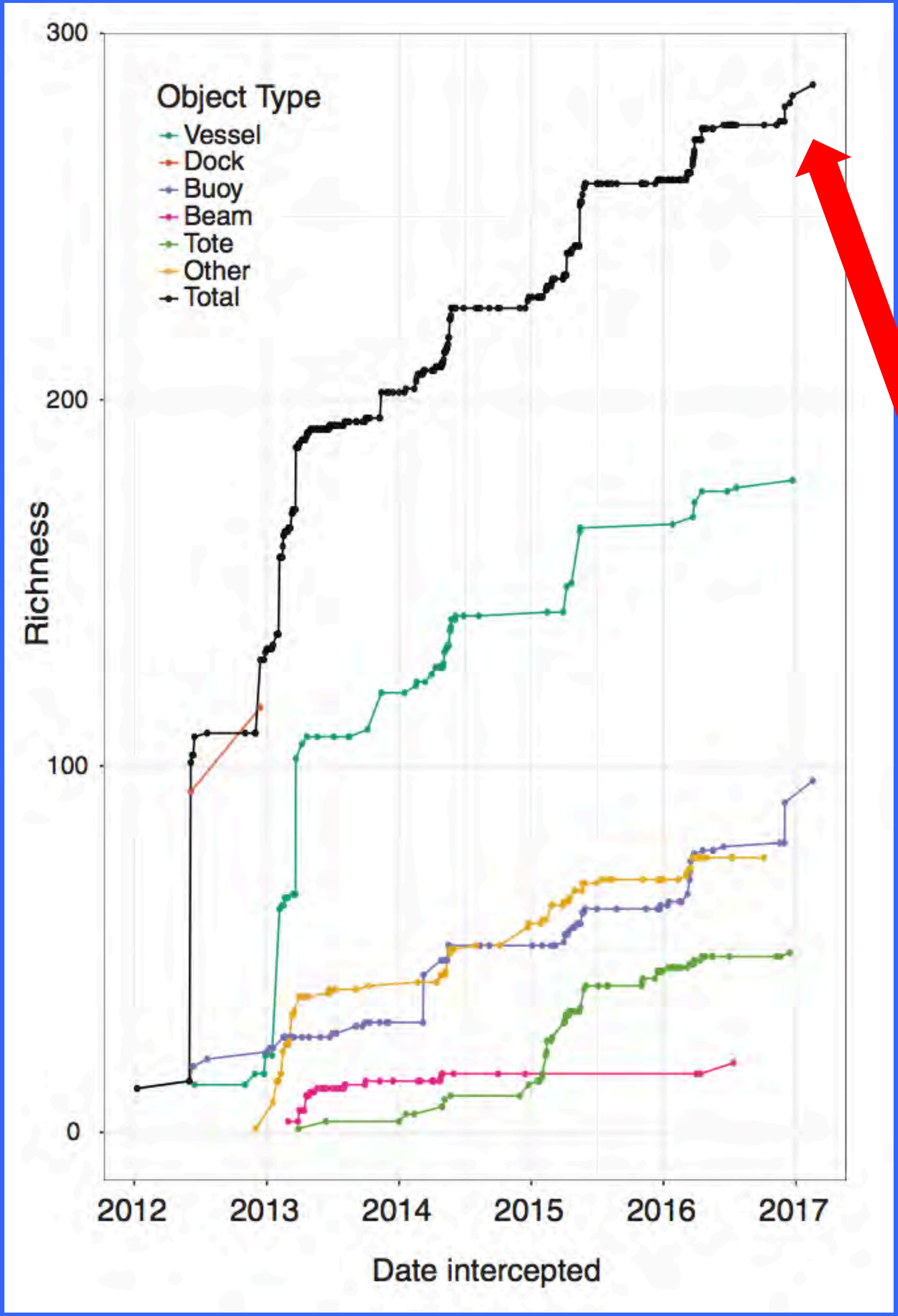
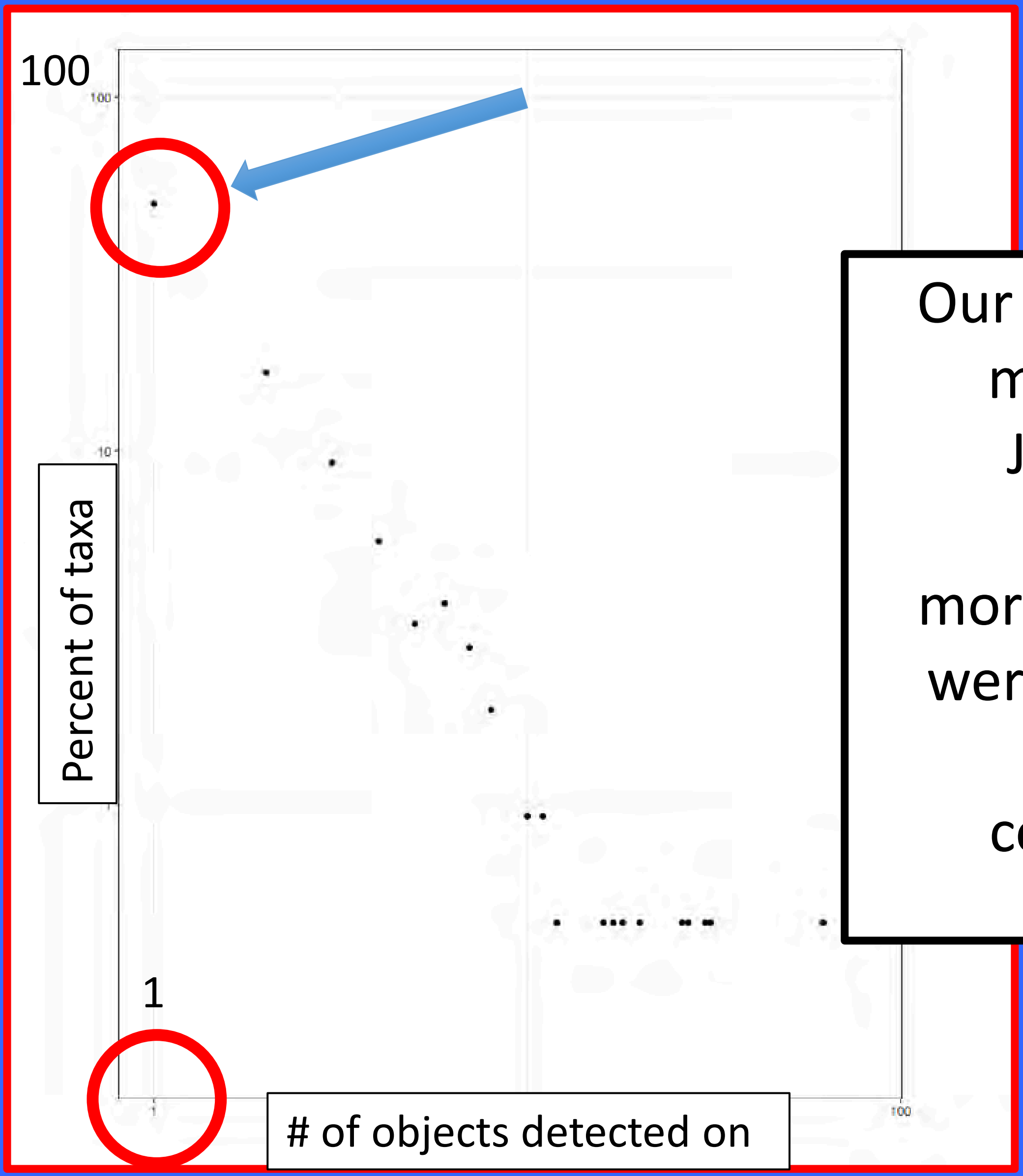


Cumulative species richness
by date and
object type

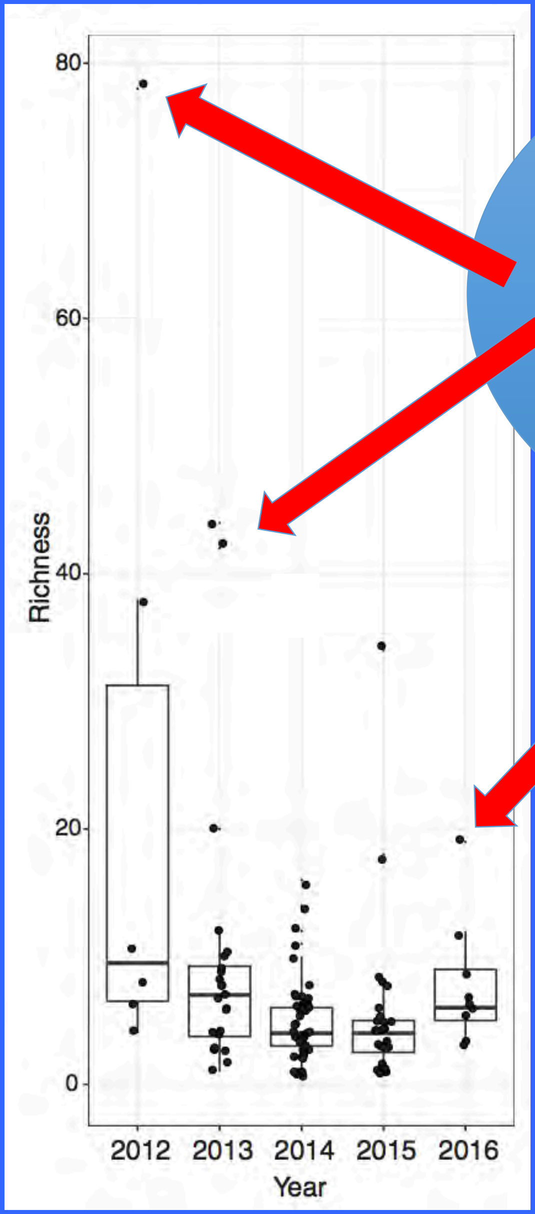
Had not yet leveled off by 2017



Our study provides only a minimal estimate of JTMD biodiversity:

more than 50% of all taxa were detected only once (and new species continued to arrive)

…. even as richness / object declined:



Peak per capita richness occurred in 2012 and 2013, with R falling below 20 species per object after mid-2015

Remarkable At Sea Long-Term Longevity

Living Japanese species continued to arrive after more than 6 years at sea -- 4 or more years longer than previously documented instances of the survival of coastal species rafting in the ocean.

(1) **multiyear growth, aging,** and unexpectedly long survival of original 2011 individuals

(2) **self-recruitment** (via non-planktonic propagules) maintaining multiple generations

---

Our knowledge is strikingly limited of the physiological processes involved in long-term survival of coastal species in the open ocean

Living Species Continue to Arrive

A buoy used in southern Hokkaido or northern Honshu landed February 28, 2018 on Long Beach, Washington with living Japanese bivalve mollusks

Pododesmus macrochisma

First JTMD record

How does modern rafting of marine objects differ from “natural rafting” ?

Historic Rafting:
wood
(trees, branches,
root masses)

Modern Rafting:
adds
anthropogenic
materials

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Wood – building wood and trees – *was largely gone by 2014* – perhaps mostly consumed by shipworms **… leaving plastic and fiberglass objects as the persistent ocean rafts**

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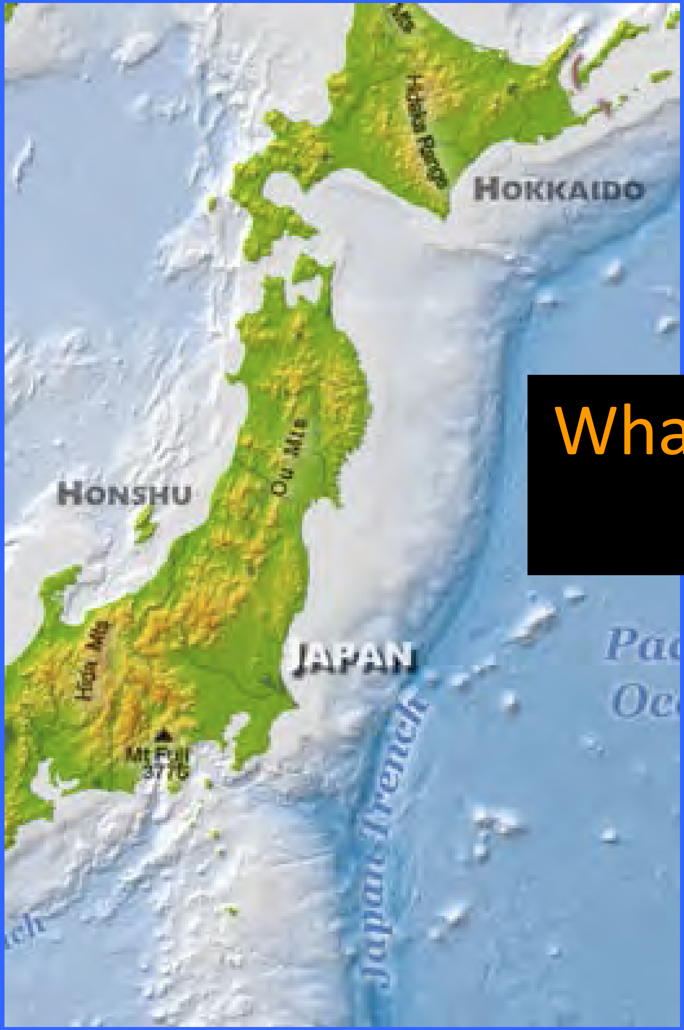
Marine debris (marine litter):
largely non-biodegradable material:
long-lasting plastic, fiberglass, and other substrates
which may differ fundamentally
in their at-sea longevity from historic rafting

How does modern rafting of marine objects differ from "natural rafting" ?

Thus, the previously unknown capacity of coastal species for extended long-term survival on a transoceanic journey was revealed by *plastic persistence:*

Anthropogenic materials have critically extended the potential for long-term and long-distance transport of non-native species

Tsunamis in Northeastern Honshu



What about historic tsunamis in Japan?

Earthquakes and Resulting Tsunamis in Northeastern Honshu
(Tōhoku region: Sanriku coast)

Date	Name	Magnitude	Wave Height	Deaths
July 9, 869	Jogan Sanriku	8.9+?	----	1,000+
Dec. 2, 1611	Keicho Sanriku	8.1	20m	5,000+
June 15, 1896	Meiji-Sanriku	8.5	38m	22,000
March 2, 1933	Sanriku	8.4	29m	3,000

Japanese Tsunamis in Northeastern Honshu: 1933 *vs.* 2011

Aomori and Iwate Prefectures

1933 tsunami (magnitude 8.4 / 29 m)

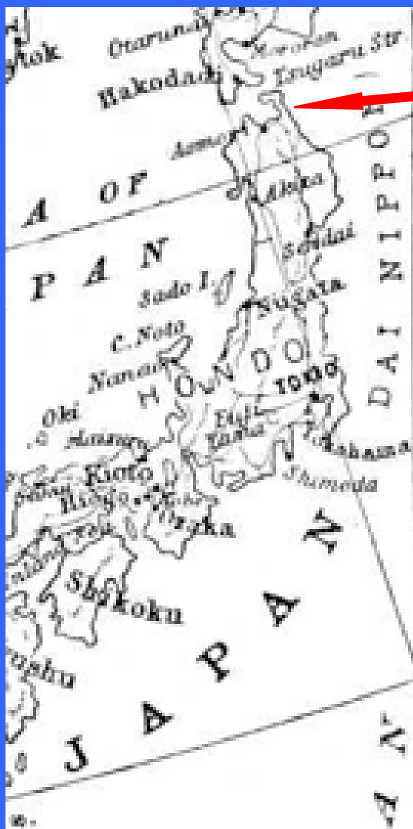
2011 tsunami (magnitude 9.0 / 30 m)

What was the scale of coastal infrastructure in 1933?

1933 Sanriku Earthquake and Tsunami

[Tōhoku region]

Undersea earthquake, 290 km east of the coast

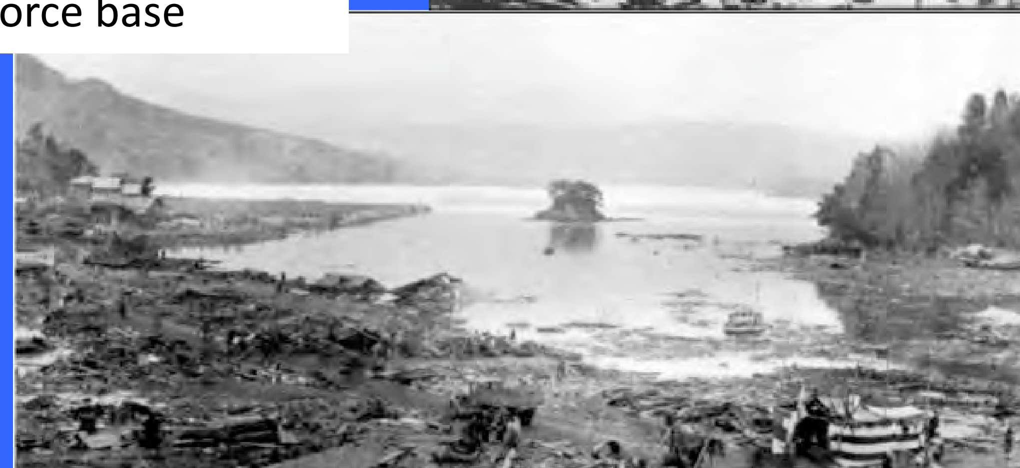


Aomori Prefecture:

Misawa:

in 1933 the airfield was a gravel runway on the beach

Today, Misawa hosts a large U.S. Air Force base



Kamaishi Harbor, Iwate Prefecture:
Tsunami Damage, 1933

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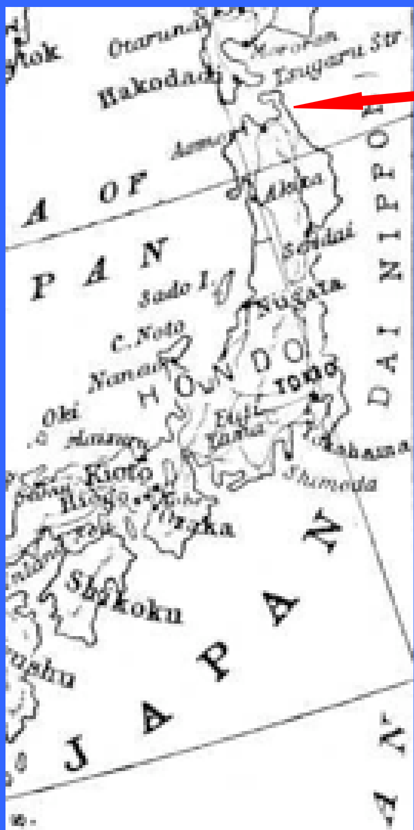


Aomori Pr

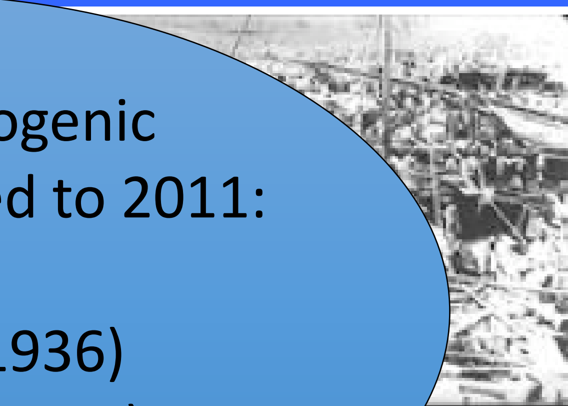
in 193

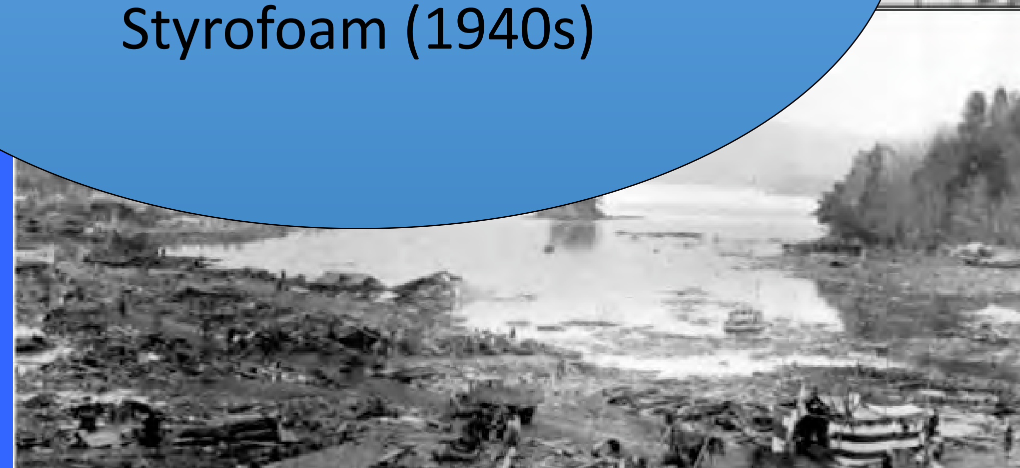
grave

Less anthropogenic material compared to 2011:

Fiberglass (1936)

Styrofoam (1940s)





Kamaishi Harbor, Iwate Prefecture: Tsunami Damage, 1933


1925

Miami Beach, Florida

Miami Beach, Florida

"In the absence of strong reductions in greenhouse gas emissions … (there will be) substantially larger increases in tropical cyclone intensities."

REVIEW

Human influence on tropical cyclone intensity

Adam H. Sobel,[1,2]* Suzana J. Camargo,[2] Timothy M. Hall,[3] Chia-Ying Lee,[4] Michael K. Tippett,[1,5] Allison A. Wing[2]

Recent assessments agree that tropical cyclone intensity should increase as the climate warms. Less agreement exists on the detection of recent historical trends in tropical cyclone intensity. We interpret future and recent historical trends by using the theory of potential intensity, which predicts the maximum intensity achievable by a tropical cyclone in a given local environment. Although greenhouse gas–driven warming increases potential intensity, climate model simulations suggest that aerosol cooling has largely canceled that effect over the historical record. Large natural variability complicates analysis of trends, as do poleward shifts in the latitude of maximum intensity. In the absence of strong reductions in greenhouse gas emissions, future greenhouse gas forcing of potential intensity will increasingly dominate over aerosol forcing, leading to substantially larger increases in tropical cyclone intensities.

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SPECIAL SECTION NATURAL HAZARDS

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SCIENTIFIC REPORTS

OPEN

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Persistent northward North Atlantic tropical cyclone track migration over the past five centuries

Lisa M. Baldini[1,†], James U. L. Baldini[1], Jim N. McElwaine[1], Amy Benoit Frappier[2], Yemane Asmerom[3], Kam-biu Liu[4], Keith M. Prufer[5], Harriet E. Ridley[1], Victor Polyak[3], Douglas J. Kennett[6], Colin G. Macpherson[1], Valorie V. Aquino[5], Jaime Awe[7,8] & Sebastian F. M. Breitenbach[9,10]

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SCIENTIFIC REPORTS

"Our results strongly suggest that future emission scenarios will result in more frequent tropical cyclone impacts on the …. northeastern United States."

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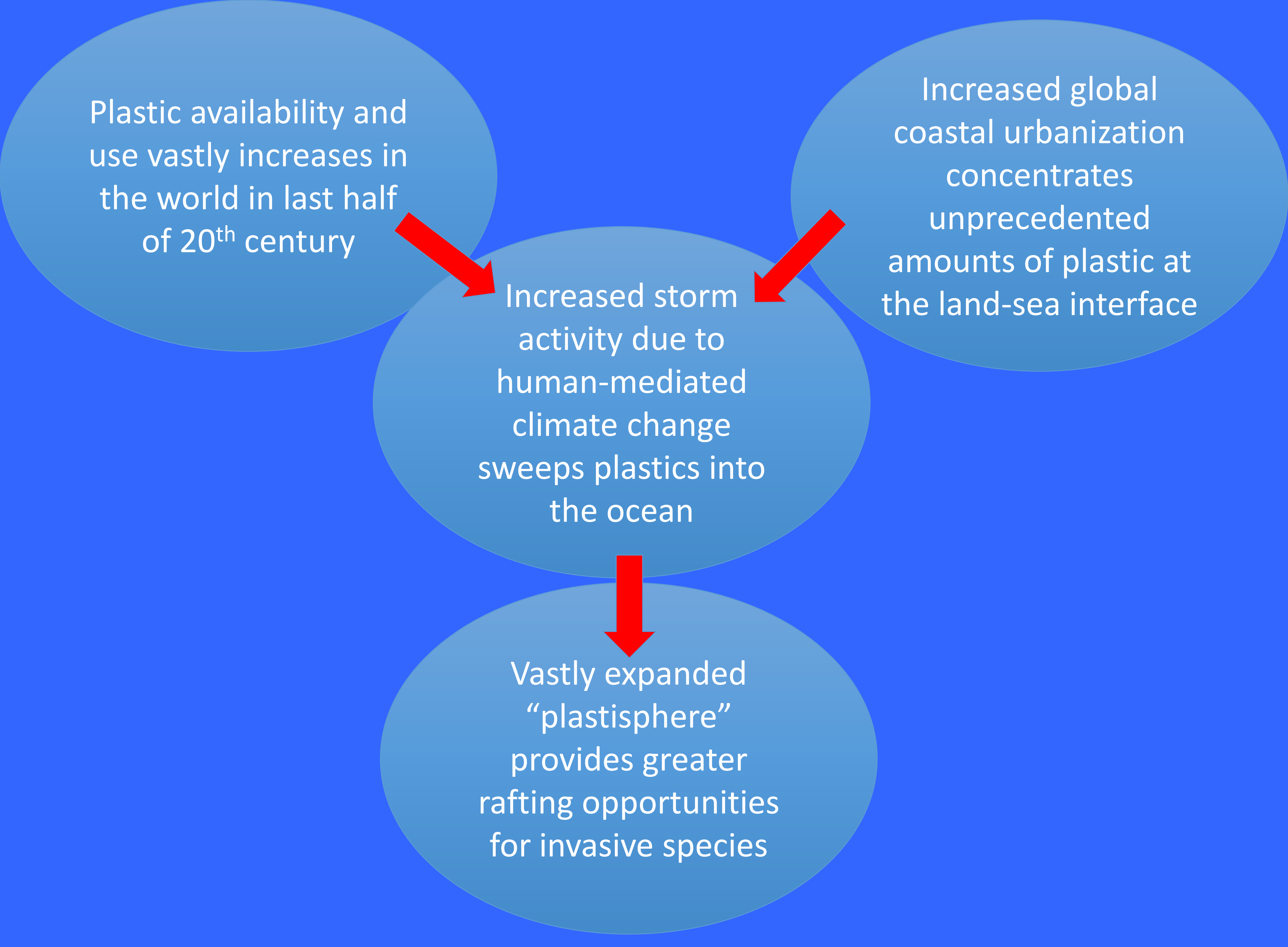
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Increased global coastal urbanization concentrates unprecedented amounts of plastic at the land-sea interface
Increased storm activity due to human-mediated climate change sweeps plastics into the ocean
Vastly expanded “plastisphere” provides greater rafting opportunities for invasive species

Marine biofouling on plastics

* **Invasions.** A growing vector for species invasions

* **Origin.** Biofouling may provide critical data on the source of marine debris, which can strongly inform focused management efforts.

* **Biofouling may alter drift modeling.** Biofouling loading and drag may critically impact models seeking to predict the longevity and fate of drifting debris

* **Biofouling increases plastic life-at-sea?** Does biofouling extend the life of plastics at sea (*via* protecting from UV exposure [decrease in UV transmittance] and reduced degradation)?

6th INTERNATIONAL MARINE DEBRIS CONFERENCE

400 Oral Presentations

170 Poster Presentations

The number of papers on non-microbial marine life present on or transported by debris:

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The number of papers on non-microbial marine life present on or transported by debris:

3

6th

INTERNATIONAL
MARINE DEBRIS
CONFERENCE

With the vast amount of debris being collected, handled, and processed, there thus appears to be opportunity to now **infuse bioforensics as a novel new direction for marine debris science**


How to navigate the preprint landscape
Tackling antibiotic use in animal agriculture
Forming the first massive black holes
Science
29 SEPTEMBER 2017
AAAS
TSUNAMI TRANSPORT
Transoceanic species dispersal
pp. 1356 & 1402