

'ADRIFT'

(Assessing the Debris-Related Impact from Tsunami) project

– outline and legacy products –

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Fisheries and Oceans Pêches et Océans
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東日本大震災と津波

GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

2011年3月11日にマグニチュード9.0の地震が発生し、最大39メートルもの高さの津波が360 km以上の東北地方の太平洋沿岸を襲った。

On March 11, 2011, a great earthquake with a magnitude of 9.0 hit the country of Japan and triggered a tsunami with waves up to max. 39 meters (130 feet) over (360 km) 200 miles of coastal line of East North of Japan mainland (*Honshu*) facing the Pacific Ocean.

Photo credit: National Geographic



津波起因海洋漂流物

JAPAN TSUNAMI MARINE DEBRIS ("JTMD")

500万トン以上のものが海に流され、太平洋上をさまよい始めた。

An estimated 5 million tonnes of debris was washed away and began drifting east across the Pacific Ocean.



Photo credit: U.S. Navy



Photo credit: Bloomberg

PERSPECTIVES

環境省による拠出金事業

Funded by Ministry of the Environment (MoE)



日本政府 Government of Japan

実施期間: 2014年7月 – 2017年3月

Duration: July 2014 – March 2017

プロジェクトで実施した各課題

RESEARCH THEMES

1. Modelling

震災起因の海洋漂流物の移動の軌跡予測モデルシミュレーション

2. Surveillance and Monitoring

漂流・漂着物のモニタリング調査

3. Risk of Invasive Species

漂流・漂着物に伴う移入種のリスク評価



海洋漂流物のモデルシミュレーション

Model Simulation of Japan Tsunami Marine Debris (JTMD)

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(海洋研究開発機構/地球情報基盤センター JAMSTEC/CEIST)



N. Maximenko, J. Hafner,
(ハワイ大学 Univ. Hawaii IPRC)

川村 英之

(原子力研究開発機構 JAEA)



国立研究開発法人
日本原子力研究開発機構
Japan Atomic Energy Agency

石川 洋一

(海洋研究開発機構 JAMSTEC)



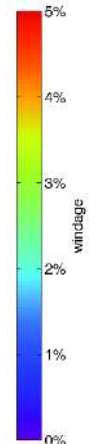
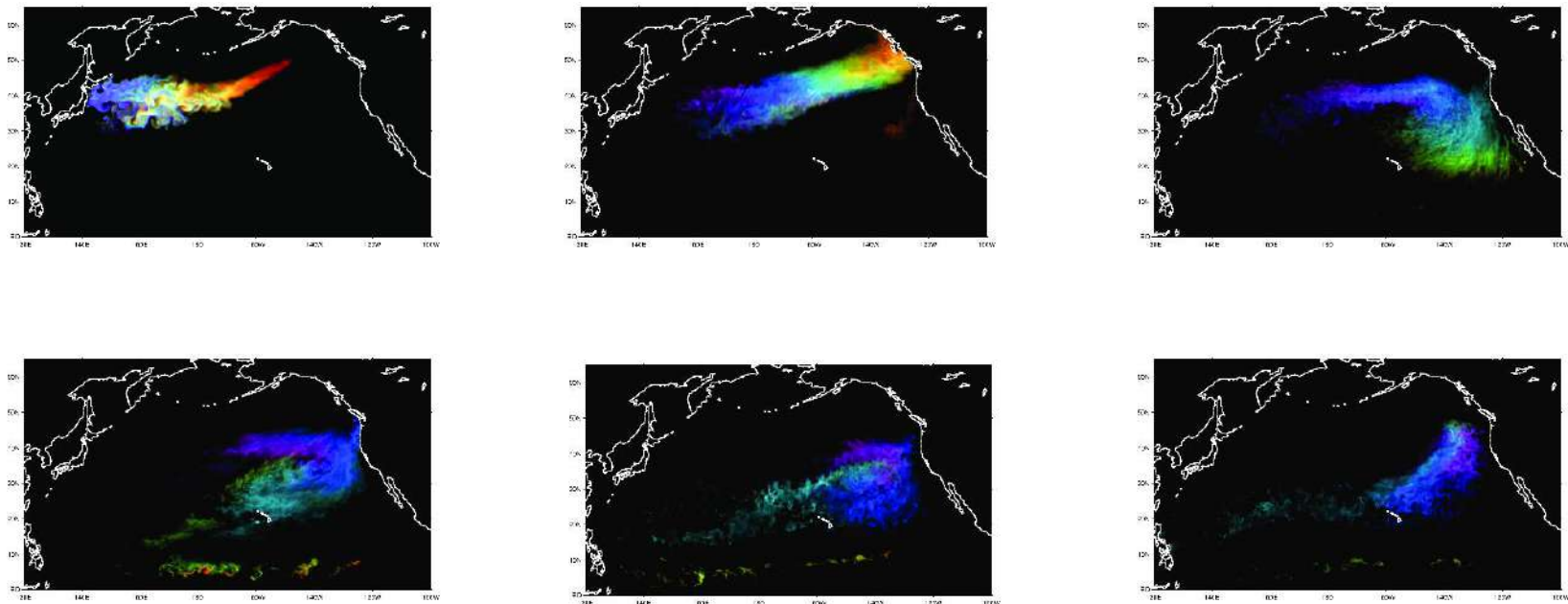
A. MacFadyen
(米国海洋大気庁 NOAA)

碓氷 典久

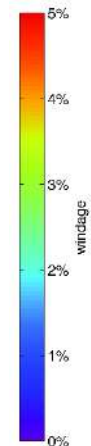
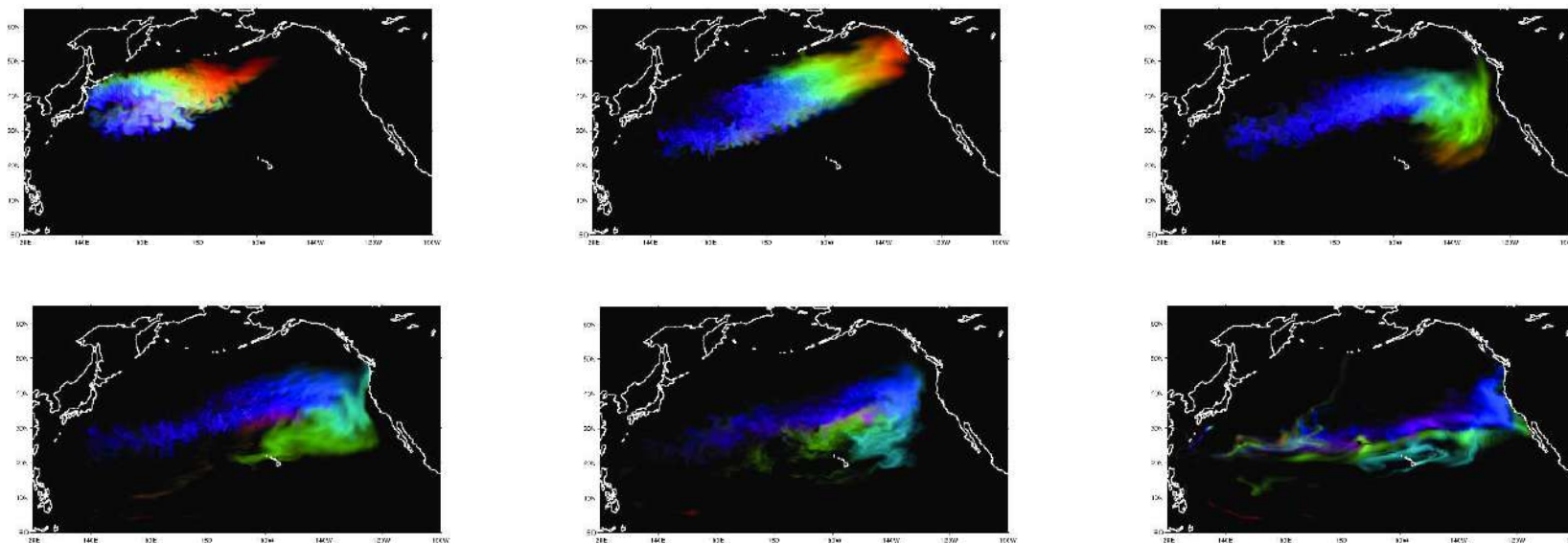
(気象庁気象研究所 MRI/JMA)



様々なモデルの比較
Inter-comparison of
various models

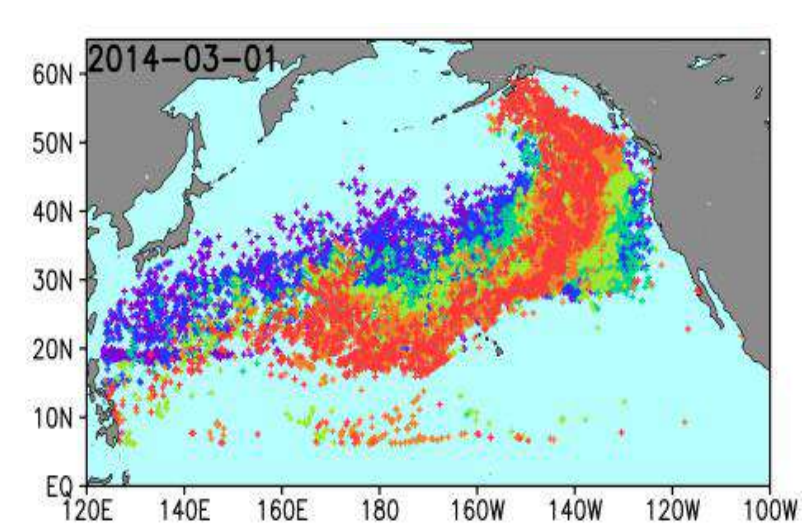
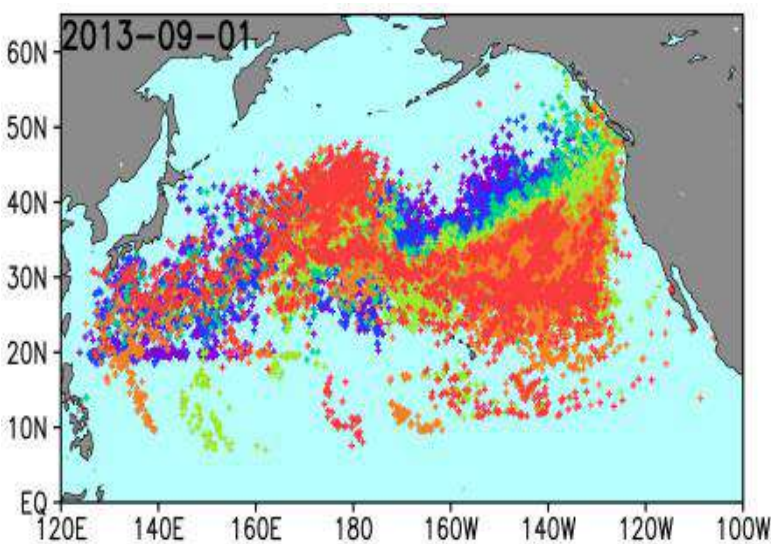
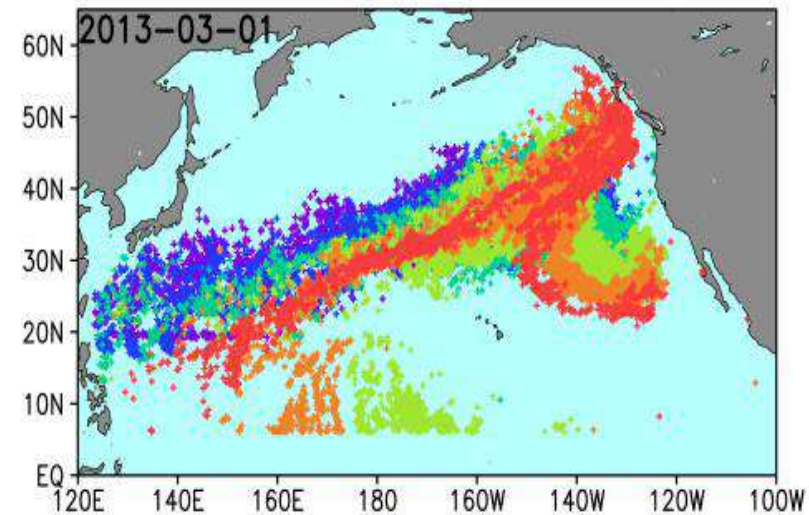
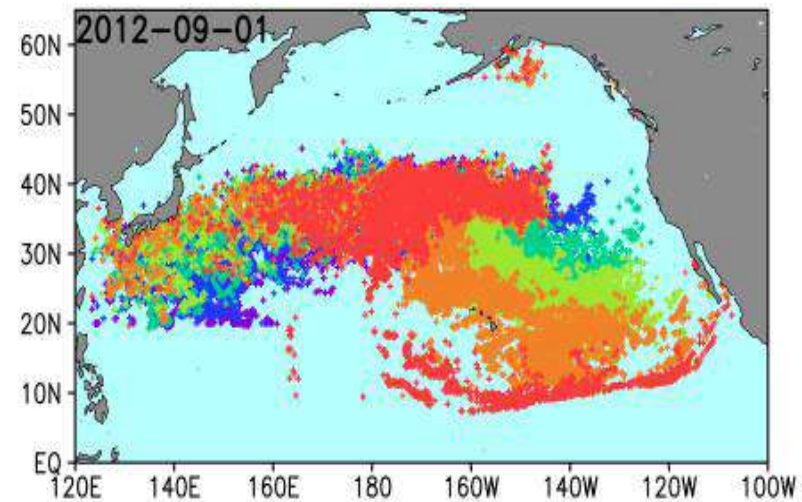
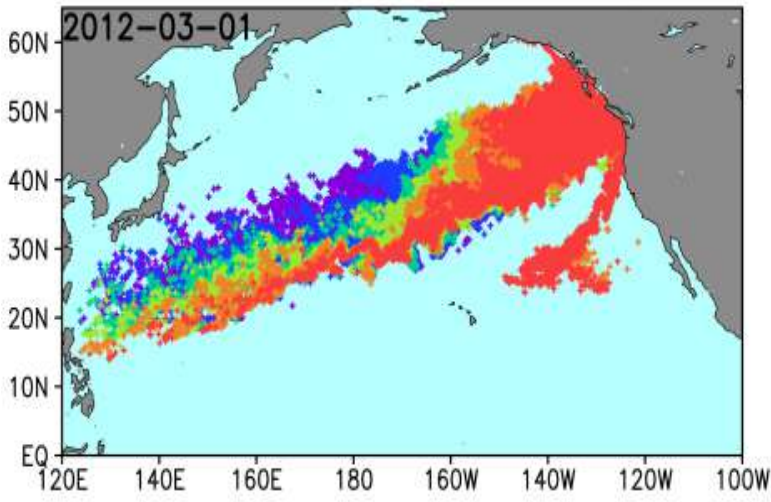
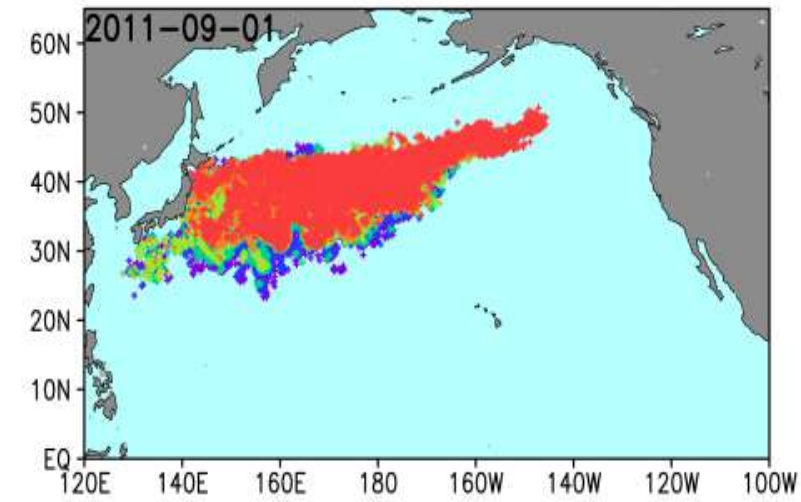


SCUD モデル(ハワイ大IPRC) SCUD model simulations by Hawaii Univ., IPRC

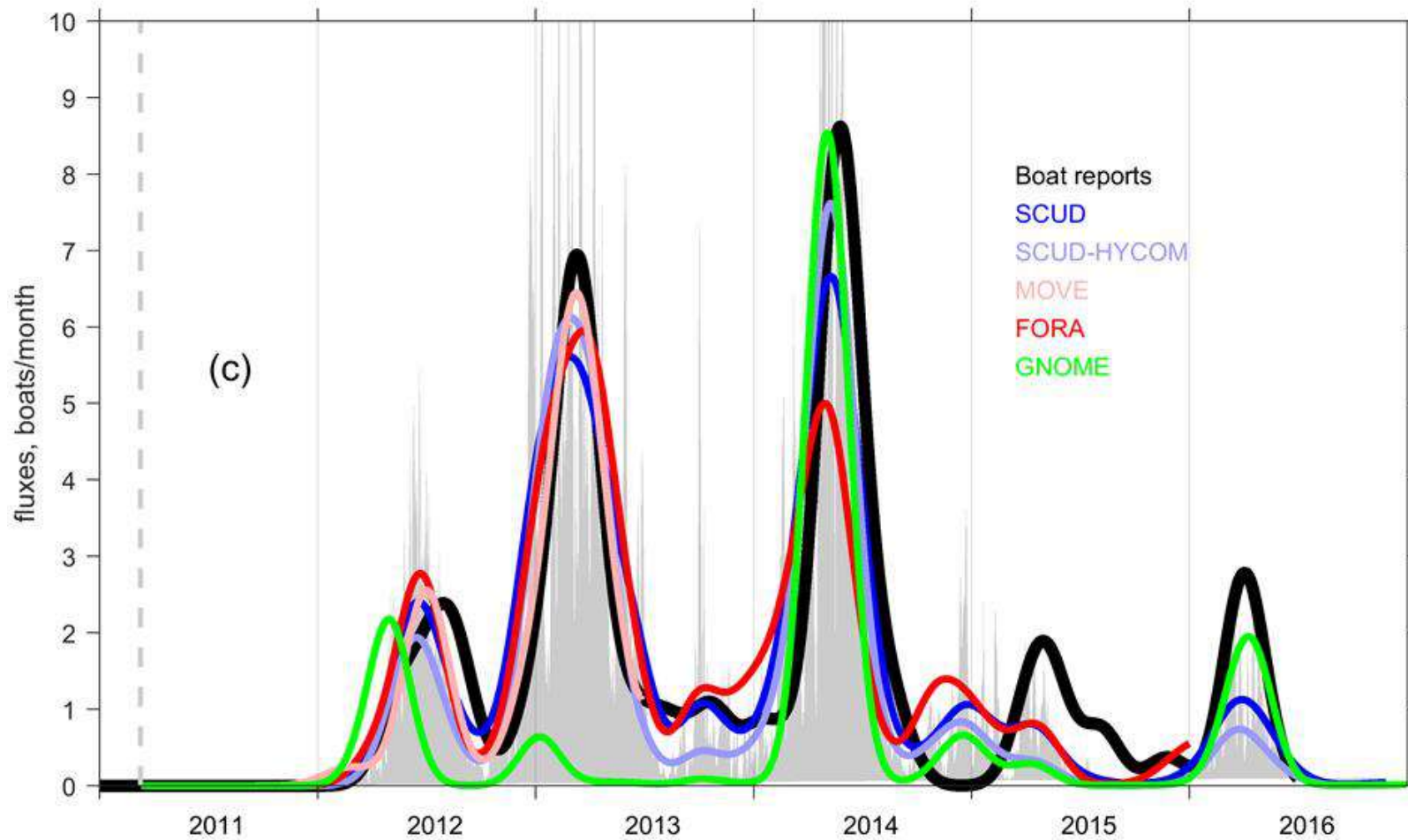


MOVE/K-7/SEA-GEARN モデル(日本合同チーム) MOVE/K-7/SEA-GEARN model simulations (Japan)

米国海洋大気庁(NOAA)のシミュレーションシステム(GNOME)による結果



GNOME model simulations by NOAA, USA. Colors indicate particle windages



日米複数のモデル(SCUD、GNOME、SEA-GEARN/MOVE-K7)による漂着物のシミュレーション結果と、北米西海岸における小型船舶漂着発見状況との比較

JTMD boat observations (black line) and scaled model fluxes on the North America west coast for multi-windage approximation with windage distribution.

Lines present timelines, smoothed with a Gaussian filter of 1.5-month half-width.

Grey background shows unsmoothed scaled SCUD solution at optimal windage.

Vertical dashed gray line marks the moment of the tsunami. Units are number of boats per a month.

北米西海岸設置のウェブカメラによる漂着物挙動解析 Webcam monitoring of landed marine debris

磯辺篤彦 Atsuhiko Isobe (Research Institute for Applied Mechanics [RIAM],
Kyushu Univ)



岩崎慎介・油布圭 (RIAM), 加古真一郎 (鹿児島大), 片岡智哉 (東京理科大)
Charlie Plybon (Surfrider Foundation OR), Thomas A. Murphy (Oregon State Univ)
and Nir Barnea (NOAA, Marine Debris Program)



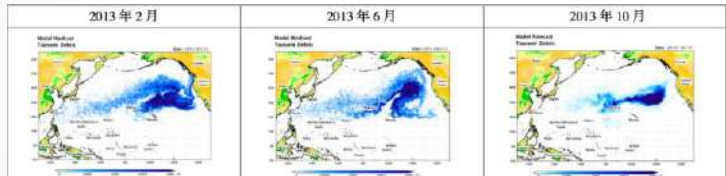
私たちの戦略
Our strategy

「震災漂着物が運ぶ外来生物は、北米ハワイの海洋・海岸生物に脅威となるか？」



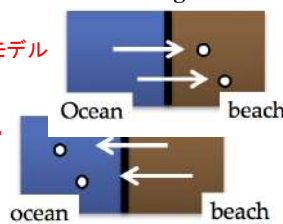
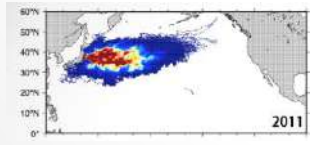
そもそもinvasive species は震災漂着物でなくても運ばれるもの。
震災漂着物由来に限定した環境影響評価ができるのか？
→ 震災漂着物の漂着場所や時期を特定することが重要

震災漂着物の漂流経路再現は、大気や海洋の同化プロダクト+粒子追跡モデルで、
そこそこいけるはず(下は震災直後に環境省が発表したもの(JIAMSTEC, 気象研, 京都大))。
ただ海岸漂着までは解像できず(波浪や海浜流)、あくまで沖合漂流量の推定である。
また再漂流も表現できず、漂着と再漂流を繰り返す海岸漂着量の評価は難しい。



Combination of simulation and webcam monitoring to evaluate the abundance of JTMD

大気や海洋の同化プロダクト+粒子追跡モデル



空撮画像(NOAA)によるモデルの妥当性評価

ウェブカメラで監視したゴミ漂着量と海況・風況データを比較しサブモデルを構築、これを組み合わせる。

Webcam monitoring

location

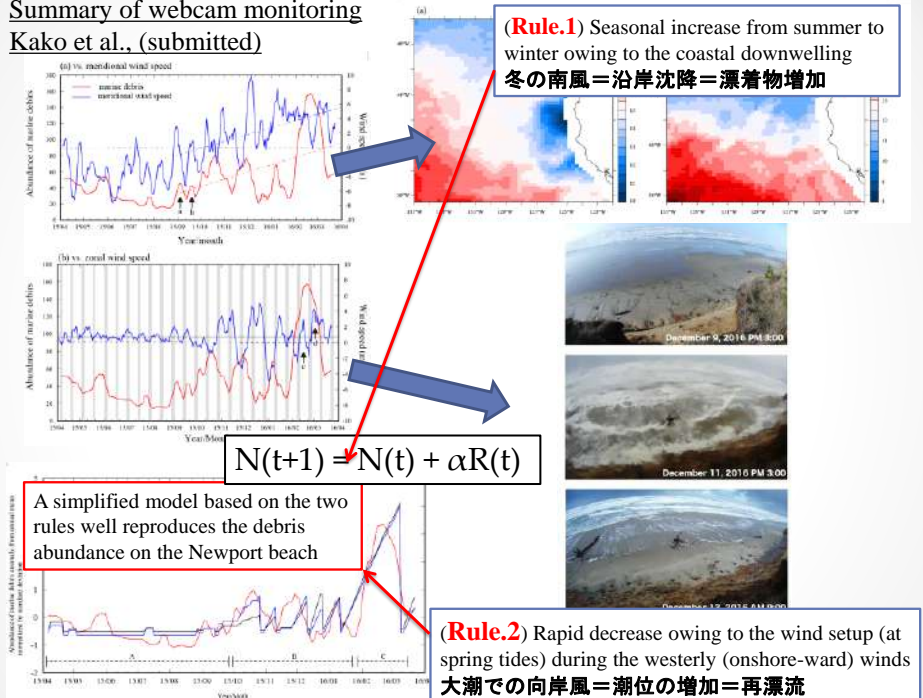
specifications

interval : 9:00~18:00 once at each hour

resolution : 1920 × 1080 pixels

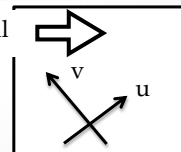
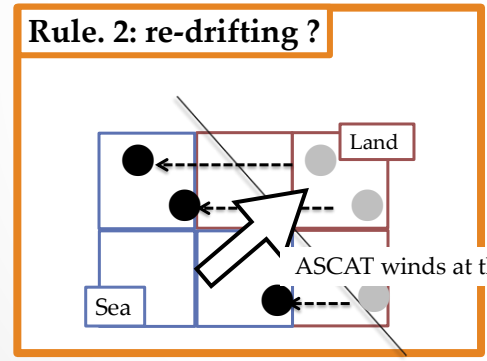
period : 2015/Apr~on-going

Summary of webcam monitoring Kako et al., (submitted)



サブモデル 岸向きの風が強い大潮時に、岸に漂着した仮想粒子を海に戻す

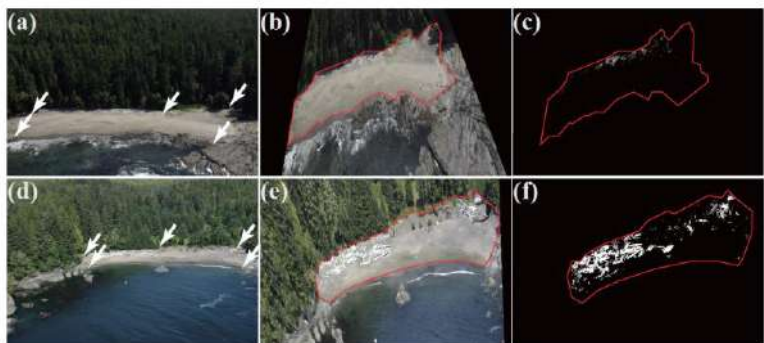
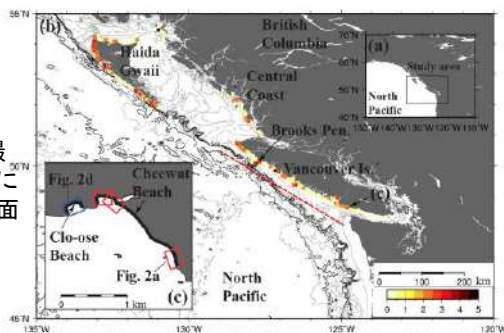
When intense **onshore-ward winds** (> average + SDV) occurred at **spring tides** (i.e., the occurrence of the **wind setup**), all debris “littered” on land cells returns to the oceanic cells.



Model validation with aerial photography using a Cessna plane

Kataoka et al. (submitted)

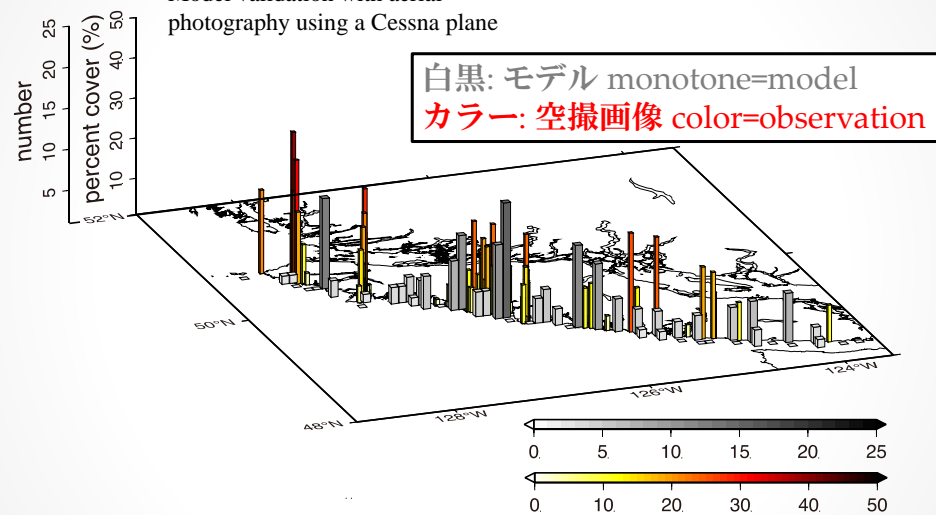
北米西海岸のセスナ機による海岸空撮写真を射影変換処理してデカルト座標に落とし込み、漂流物の被覆面積と海岸面積の比を求めた。Using the aerial photographs, we computed the ratio between areas of beach litter and beaches



観測データとの比較

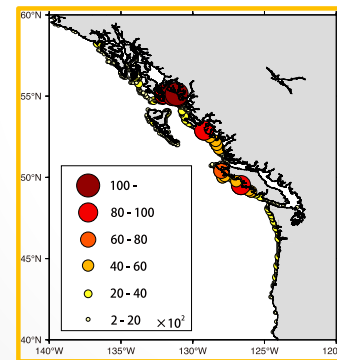
2014/10/7, 2014/12/3

Model validation with aerial photography using a Cessna plane



Conclusions

- A webcam-based sub-model was combined with a particle tracking model to estimate the abundance of 3.11 tsunami debris washed ashore on the US and Canadian beaches.
- In total, **30,000 tons** (2%) of debris potentially exist on the beaches at the present time.
- The model result states that the invasive species carried by tsunami debris were unlikely to wash ashore widely on the entire US and Canadian beaches. They have been washed ashore on the relatively **narrow area (<1000 km)** around the **south of BC and the north of WA**, which **might act as a “gate”** of the invasive species carried by the tsunami debris.



震災漂流物のうち2%程度が、米国とカナダの国境1000km程度の海岸に集中して漂着したことが示唆された。この場所で日本原産の「外来種」が多く確認されるならば、それは震災漂流物が運んだ可能性が高い。

The Transport of Marine Life Across the Ocean on Tsunami Marine Debris

東日本大震災による津波にともなう漂着物がもたらした
海洋無脊椎動物の越境移動について

James T. Carlton (Williams College, USA)

Williams

John Chapman

Jonathan Geller

Jessica Miller

Gregory Ruiz

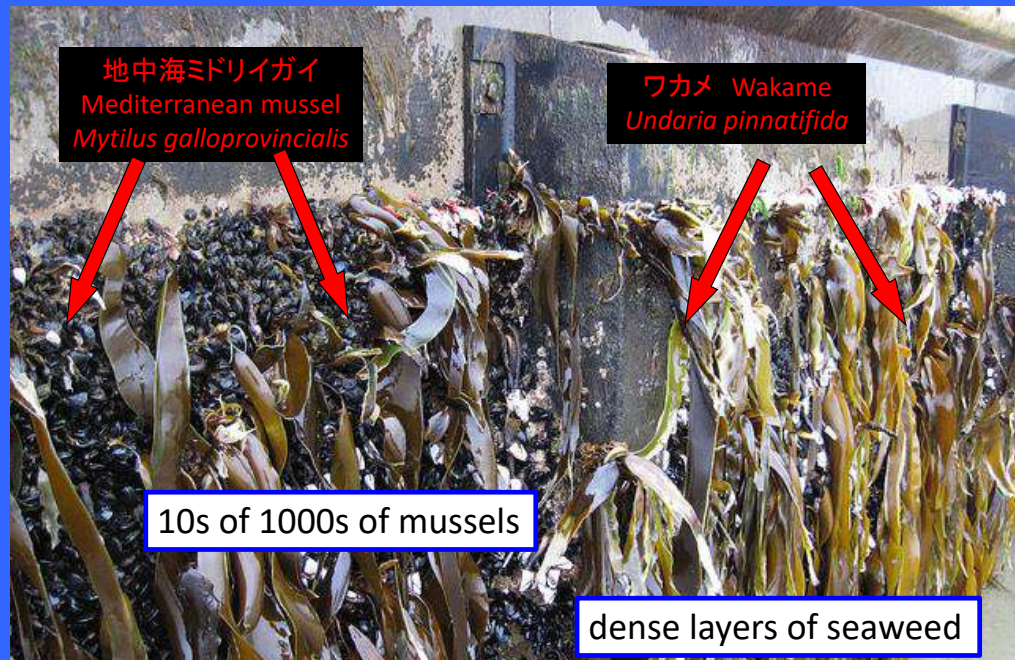
Oregon State University

Moss Landing Marine Laboratories

Oregon State University

Smithsonian Environmental Research Center





Examples of coastal organisms on "Misawa 1": Landed Agate Beach, Oregon, June 4, 2012

Sea urchin *Temnotrema sculptum*
 Sea cucumber *Havelockia versicolor*
 ECHINODERMATA
 Sea slug *Styrodonta*
 Jingle shell *Anomia cytaeum (chinensis)*
 Chiton *Mopalia seta*
 Snail *Mitrella moleculina*
 MOLLUSKS (12 species)
 Limpets: *Lottia sp.*, *Nipponacmea habei*
 Sea anemone *Metridium senile*
 Polychaete worms (28 species)
 Starfish *Asterias*
 Crab *Megabalanus*
 Amphipods *Caprella*
 Bryozoans *Tricellaria*, *Cryptosula*
 Syllidae

三沢浮き桟橋1に付着していた 128種の日本由来の海洋生物が 北米に到着した
128 different species of Japanese animals and plants crossed the ocean to North America on "Misawa 1"

「移入種」として良く知られた生物が見つかった
 Some of these species were well-known "invasive" species

WANTED DEAD OR ALIVE!
 THE NORTHERN PACIFIC SEASTAR
Asterias amurensis
 ヒトデ Seastar *Asterias amurensis*

WATCH FOR THE INVASIVE KELP
 UNDARIA PINNATIFIDA (WAKAME)
 海藻 Seaweed *Undaria pinnatifida*

Wanted dead, not alive INVADING SPECIES
 Shore Crab *Hemigrapsus sanguineus*
 磯ガニ? Shore Crab *Hemigrapsus sanguineus*

GUIDE TO MARINE INVADERS IN THE GULF OF MAINE
 Caprella mutica
 spiny red Caprellid amphipod, skeleton shrimp
 ワレカラ Skeleton Shrimp *Caprella mutica*



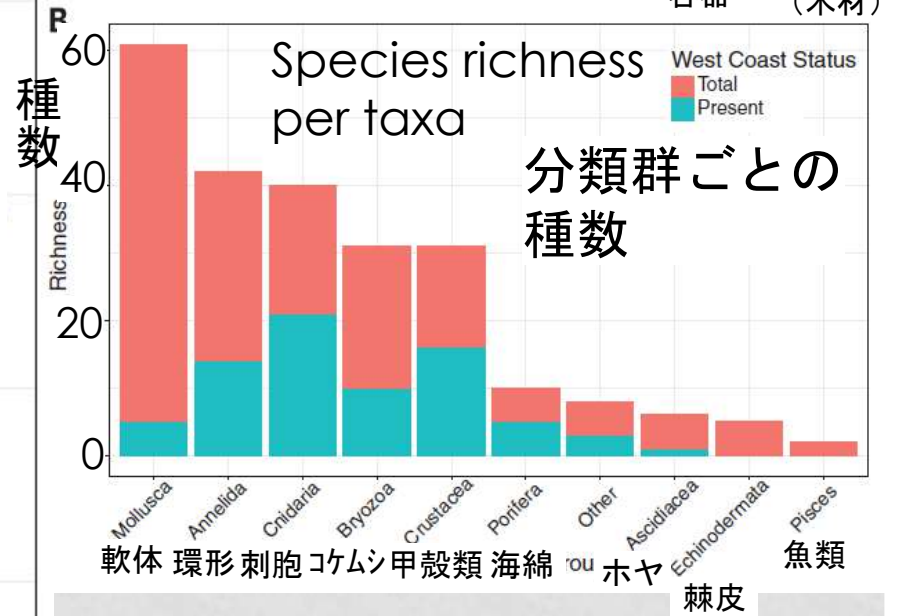
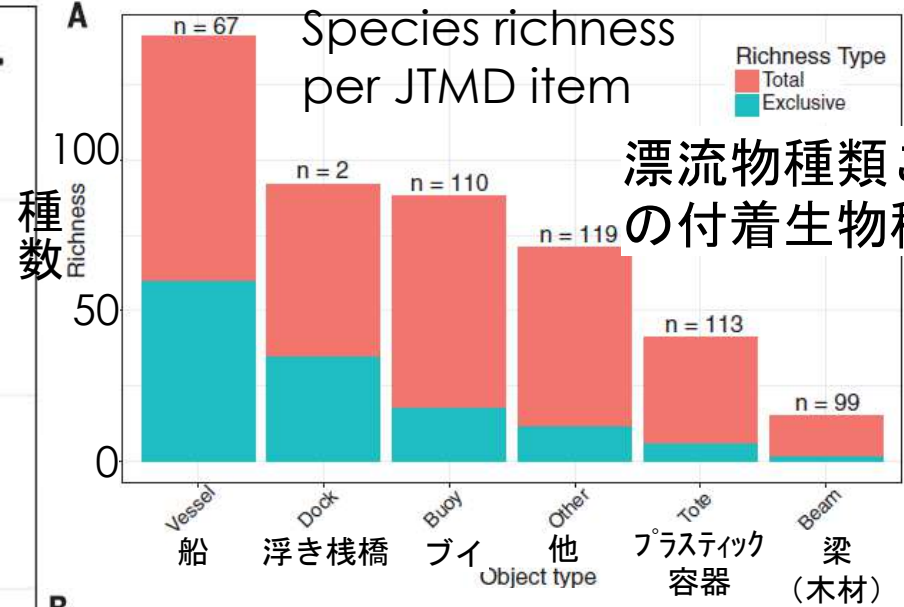
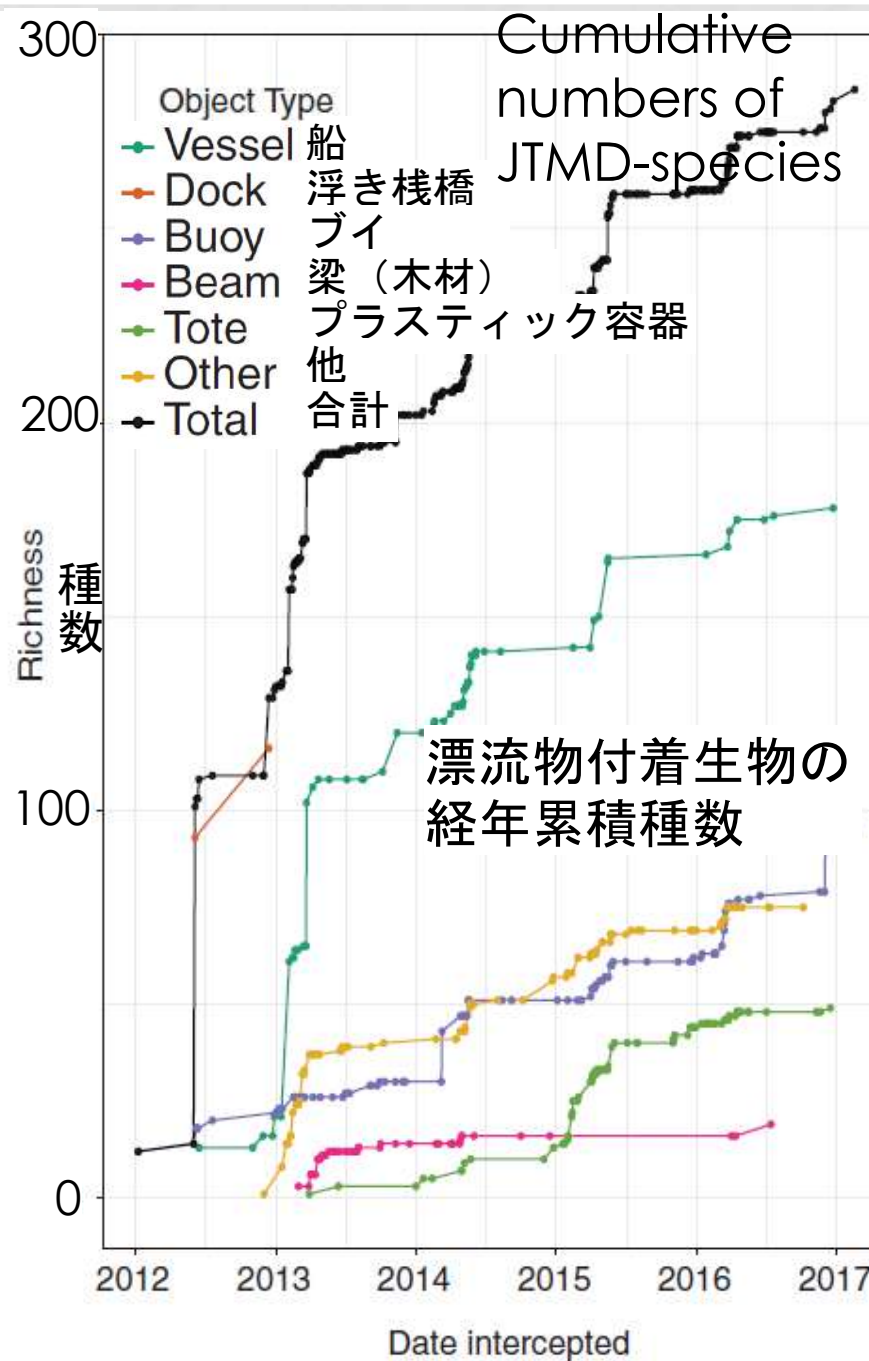
RESEARCH

BIOGEOGRAPHY

Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography

James T. Carlton,^{1,2*} John W. Chapman,³ Jonathan B. Geller,⁴ Jessica A. Miller,⁵ Deborah A. Carlton,¹ Megan I. McCuller,^{1†} Nancy C. Treneman,⁵ Brian P. Steves,⁶ Gregory M. Ruiz^{6,7}

The 2011 East Japan earthquake generated a massive tsunami that launched an extraordinary transoceanic biological rafting event with no known historical precedent. We document 289 living Japanese coastal marine species from 16 phyla transported over 6 years on objects that traveled thousands of kilometers across the Pacific Ocean to the shores of North America and Hawai'i. Most of this dispersal occurred on nonbiodegradable objects, resulting in the longest documented transoceanic survival and dispersal of coastal species by rafting. Expanding shoreline infrastructure has increased global sources of plastic materials available for biotic colonization and also interacts with climate change-induced storms of increasing severity to eject debris





漂着物付着生物の多様性 - 海藻 -

川井浩史・羽生田岳昭(神戸大学)

ゲイル ハンセン (オレゴン州立大)

Species and genetic diversity of seaweeds on Japanese tsunami debris

Hiroshi Kawai & T. Hanyuda (Kobe University)

Gayle Hansen (Oregon State University)



Diversity of JTMD-Algae (macrophytes)

津波漂流物に付着していた海藻の多様性

緑藻 Green algae



アナオサ



Ulva simplex



オオバアオサ

ウスバアオリ



褐藻 Brown algae



ワカメ



マツモ



カヤモノリ



ウスカヤモ



カウルシグサ



ウルシグサ



ムチモ



セイヨウハバブuri

Non-native species in west coast of North America

紅藻 Red algae



スサビノリ



ダルス



ベニスナゴ



アカバ



ヒラムカデ



オオバツノマタ



クロバギンナンソウ



ツルツル

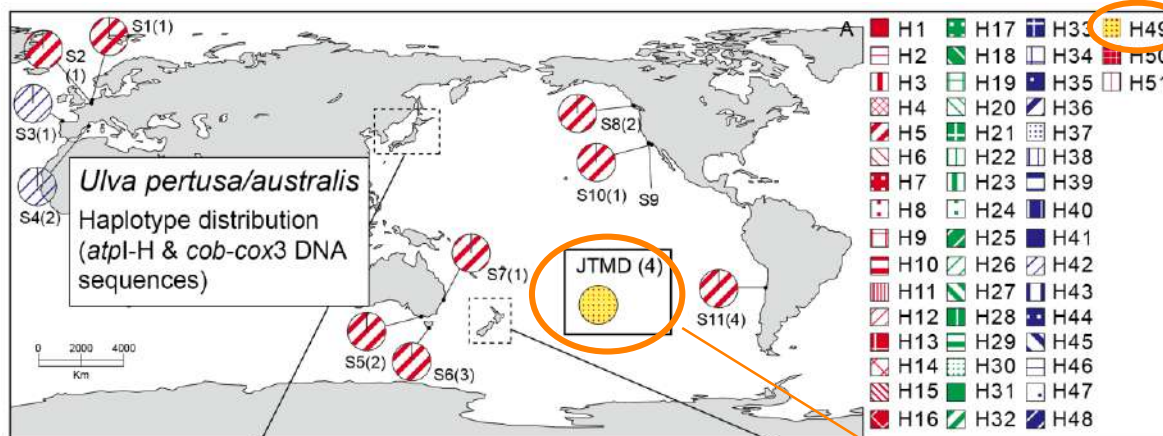
Non-native species in west coast of North America

東北沿岸, 津波漂流物付着, 北米西岸の海藻類集団の遺伝子比較
Comparisons of specimens from Tohoku region, JTMD and North America

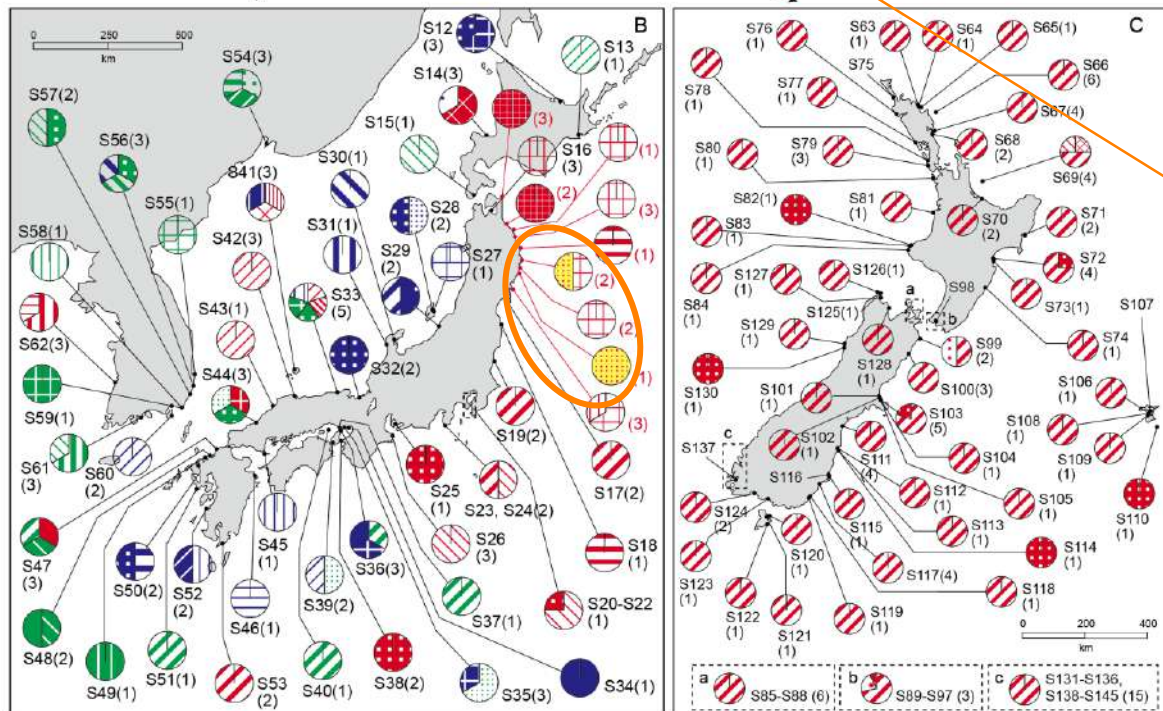


緑藻アナオサの各地域集団の遺伝的多様性の解析

漂着した船名不詳の破損した漁船は東北沿岸に由来することが確かめられた



Origin of an anonymous boat carrying yellowtail jacks and banded knifejaw fish was confirmed to be originated from Tohoku region by the genetic type of the associated *Ulva* species.



Haplotypes based on mitochondrial *atpI-H* & *cob-cox3* gene DNA sequence

代表的な津波漂流物付着海藻の同定のためのパンフレットの作成・配付

Identification guide of seaweeds on Japanese tsunami debris



Floating dock originated from Misawa Port and stranded to Oregon coast in 2012. Its surface was covered with seaweeds, debris and benthic animals. Photographs by Oregon State University.

Since 2012 marine debris caused by the 2011 Great East Japan Earthquake and Tsunami has been arriving on Northeastern Pacific shores. Often healthy seaweeds (marine macroalgae) were attached to them, which may become introduced to the Northwestern Pacific coasts. To date, about 80 species have been identified on debris based on morphological characters, and about 30 of the larger forms have been genetic analyzed for confirmation. Since many of these species do not yet occur in the NE Pacific, their introduction and dispersal could cause considerable impacts to the ecosystem. To help prevent the introduction and possible invasion of these species, it is important that any new recruitment of these species is discovered so that measures can be taken to minimize their spread.

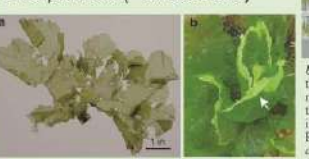
This identification guide provides information for morphologically identifying some of the most prominent species of seaweeds found on the marine debris.

Representative seaweed species found on the Japanese tsunami debris along the Washington and Oregon coasts and identified by morphology and genetic analyses. The species shown in bold are described in this brochure.

Green algae: *Biflingia nitida*, *Bryopsis plumosa*, *Chaetomorpha linum*, *Cladophora albida*, *Cladophora vagabunda*, *Codium fragile*, *Ulva lactuca*, *Ulva linza*, ***Ulva pertusa (=U. australis)***, *Ulva prolifera*, *Ulva stipitata*.
Brown algae: *Astaria crassifolia*, *Astiphanes japonica*, *Codium constricta*, *Dennanthes japonica*, *Ectocarpus communis*, *Ectocarpus crassicaulis*, *Falkenbergia irregularis*, *Falkenbergia mitchelliae*, *Kueckelia sphinosa*, ***Mutino cylindricus***, *Petalonia farcosa*, *Petalonia zosterifolia*, *Petroderma maculiforme*, *Punctaria latifolia*, *Saccarina japonica*, ***Scytosiphon gracilis***, *Scytosiphon lomentaria*, *Sphacelaria rigida*, *Undaria pinnatifida*.

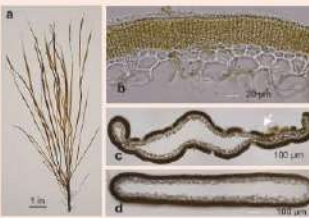
Red algae: *Bargia fasciolaria* complex, *Ceramium cimbriacum*, ***Chondrus yendoii***, *Colacoclonia* sp., *Cryptopleura raphrochloana*, *Grateloupia livida*, *Grateloupia muricata*, *Neodilsea yendoana*, *Falkenbergia pinnata* auct. japon., *Polysiphonia boreana*, *Polysiphonia morrowii*, *Pyropia yezoensis*, *Schizymenia dubyi*, *Tsunamiella transpacifici*.

Ulva pertusa (=U. australis)



Ulva pertusa (=U. australis) forms distromatic membranous thallus. The species resembles *U. lactuca*, but tends to have more perforation of thallus. Original distributional range of the species is Northwestern Pacific but the species has been introduced to wide ranges in the Pacific and Atlantic coasts. Recently the species was suggested to be synonymous to *U. australis* by genetic analysis.

Scytosiphon gracilis



Scytosiphon gracilis forms gregarious, linear saccate thalli. The species resembles *Scytosiphon lomentaria*, but differs in having more flattened thalli without constrictions and forming plurilocular gametangia lacking paraphyses (ascocysts). The thalli are basically hollow, but may become partly solid. The original distributional range of the species is Northwestern Pacific Ocean, but the species has been introduced to Baja California and Chile.

Undaria pinnatifida

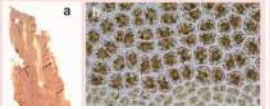


Undaria pinnatifida (wakame) is an annual kelp having a distinct midrib and lobed membranous blade. When mature, sori are formed along the side of stipe and the portion becomes ruffled. The blade has gland cell and hair conceptacles on the surface. This is an economically important species in Northeastern Asia and widely cultivated in Japan, Korea and China. The species has been introduced worldwide including California, but has not been reported from north of Oregon.

Saccarina japonica (makombu) is a basically biennial kelp that may exceed several meters in length. The blades have undulations when young, but later becomes smooth. This is an economically important species in NE Asia and widely cultivated in Japan, Korea and China. Externally, the young thalli resemble *S. latissima*, but when mature, the stipes are shorter and the blade base is narrower (more acute) than in most other *Saccarina* species occurring in the NE Pacific. The species has not been reported from eastern Pacific coasts.

Publication and distribution of identification guide of representative seaweeds on JTMD

Pyropia yezoensis

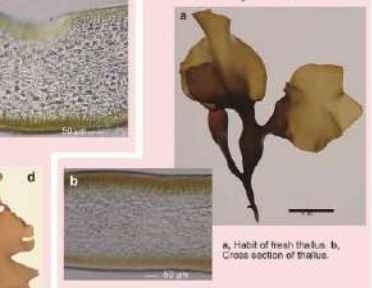


Neodilsea yendoana



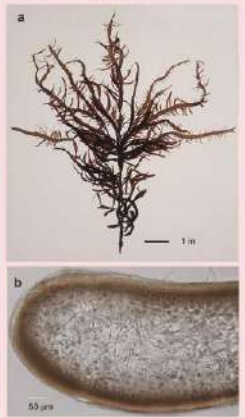
Neodilsea yendoana is a large annual red alga that is ovate to obovate in shape with a wedge-shaped basal portion. The thalli are yellowish to dark red in color, undulated and easily disintegrate. The species has not been reported from eastern Pacific coasts. Externally the species resembles some forms of Northeastern Pacific *Grateloupia doryphora* but the thalli of *Neodilsea* are somewhat bulbate and not smooth as in *Grateloupia*.

Chondrus yendoii



Chondrus yendoii has gregarious tough, simple or irregularly branched thalli. The upright thalli are annual, but the basal system is perennial. The species resembles some forms of *Macozella parkii*, a species that occurs in the high intertidal of OR and WA, but it is about twice the size. In Alaska, it resembles several species, including *Macozella phyllocarpa*. The species has not yet been reported from Northeastern Pacific.

Grateloupia livida



Grateloupia livida is a red alga having branched strap-shaped thalli with acute apices. The thalli are simple to one to two times branched, but highly variable in the external morphology. The thallus frequently forms adventitious branched on the edges. The inner medullary layer is filled with relatively densely intertwined filaments. The species is distributed in Northeastern Asia, and has not been reported from Northeastern Pacific.

Schizymenia dubyi bears a short stipe and an ovate to broadly lanceolate foliose thallus that can be deeply split. The thallus is soft and slippery when young, but later becomes somewhat leathery. The inner medullary layer is filled with loosely intertwined filaments. Characteristic gland cells are formed in the cortical layer. The species has a heteromorphic life history alternating between an upright gametophyte and a crustose sporophyte. In female thalli, carpogonophytes are thickly dispersed in the subcortex giving the thallus mottled appearance. The species has a relatively broad distributional range. However, in the Northeastern Pacific, it has only been found in California.

Species Risk Assessment

種としての津波海洋漂流物付着生物種のリスクアセスメント

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Williams

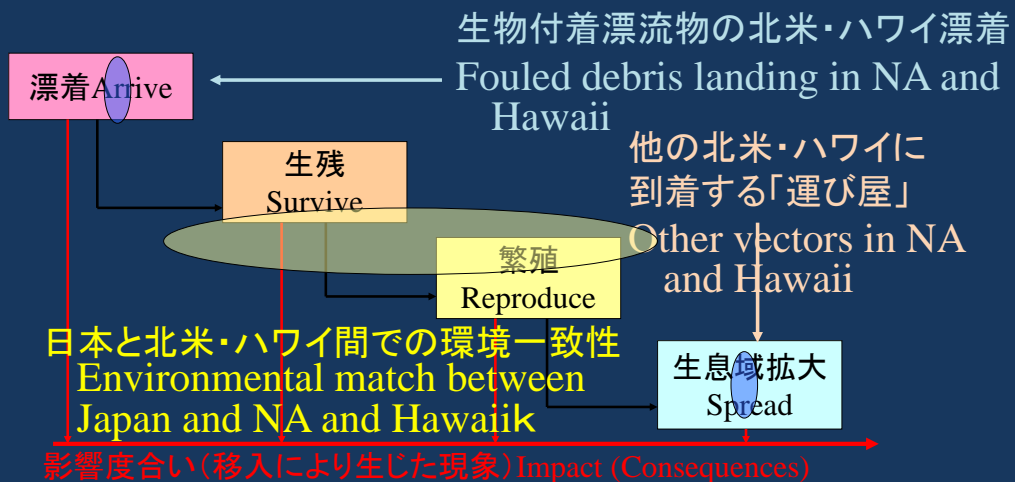


Fisheries and Oceans Canada | Pêches et Océans Canada



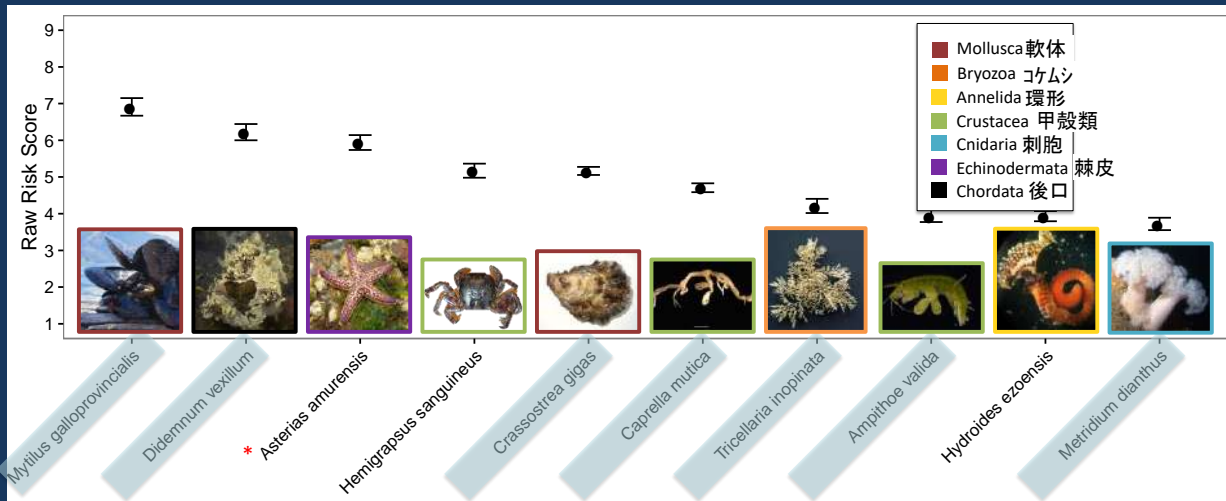
津波海洋漂流物を対象にした評価方法

So for Japanese Tsunami Debris



多くのものは既に北米西海岸やハワイに移入している

Many of these are already present



Photos from iucngisd.org, cabi.org, invasions.si.edu, marlin.ac.uk, and Kishikawa (2011)

カナダ海洋移入種選別ツール

Canadian Marine Invasive Screening Tool (CMIST)

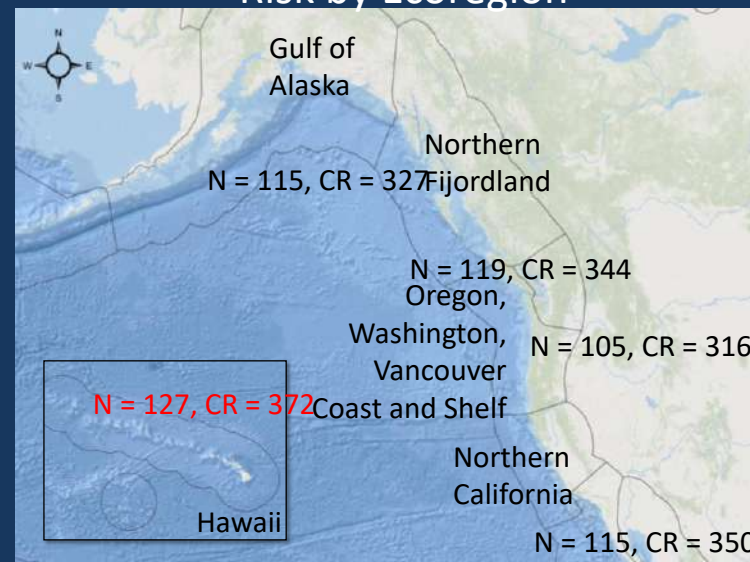
- 移入可能性とその影響に関するリスク評価のための選別ツール
Screening tool that evaluates risk based on invasion likelihood and impacts
- 17個の質問で三段階にランク付けを行う。
17 Questions scored from low (1) to high risk (3):
 - 現在の状況 Present status in the area
 - 導入される割合・速度 Rate of introduction
 - 生存 Survival
 - 生息の確立 Establishment
 - 拡大 Spread
 - 影響 Impact
- 評価者による不確実性を評価する
Captures assessor uncertainty
- 漂流物に見つかった132種の無脊椎動物について評価を試みた
We applied to 132 invertebrates on debris



CSAS Science Advisory Report 2015/04
Drolet et al. (2016) Biological Invasions 18

生態区分(エコリージョン)毎のリスク評価

Risk by Ecoregion



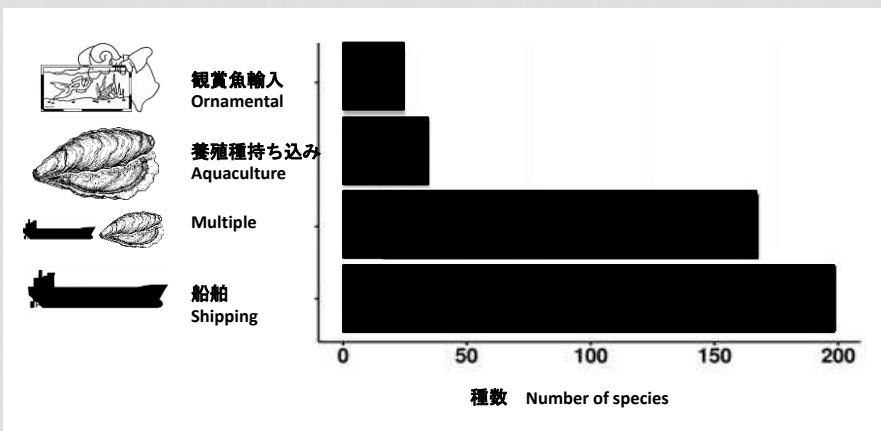
Spalding et al. (2007) BioScience 57 (7)

移入種の“運び屋”（ベクター）としての津波漂流物のリスクアセスメント
VECTOR RISK ASSESSMENT: HOW DOES TSUNAMI DEBRIS COMPARE?

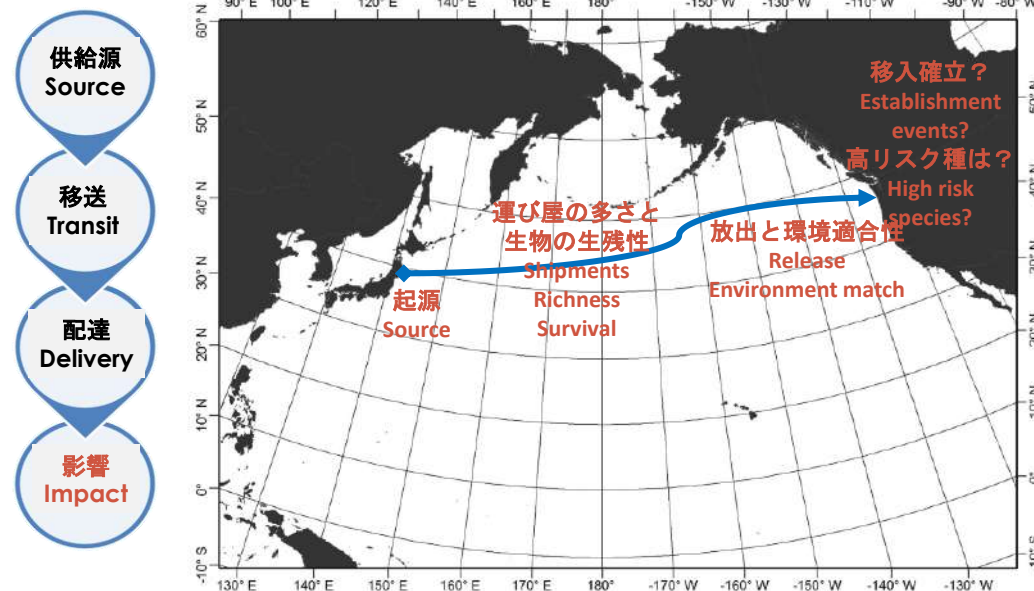
Dr. Cathryn Clarke Murray
PICES Project Scientist (presently, DFO)



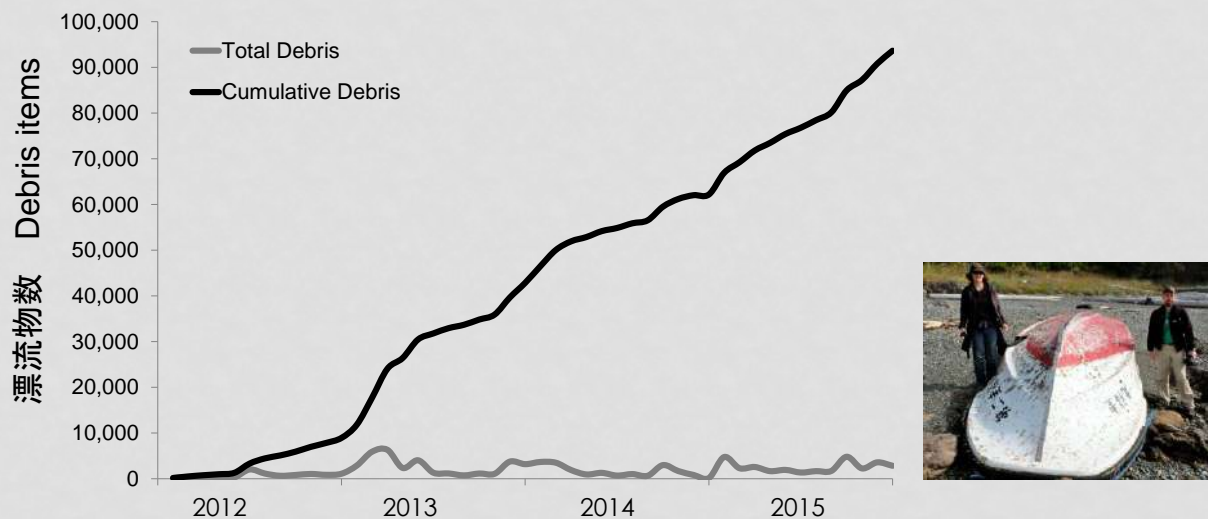
200種以上の生物が既に他の経済行為により導入されている。
 MORE THAN 200 SPECIES HAVE ALREADY BEEN
 INTRODUCED BY OTHER ACTIVITIES



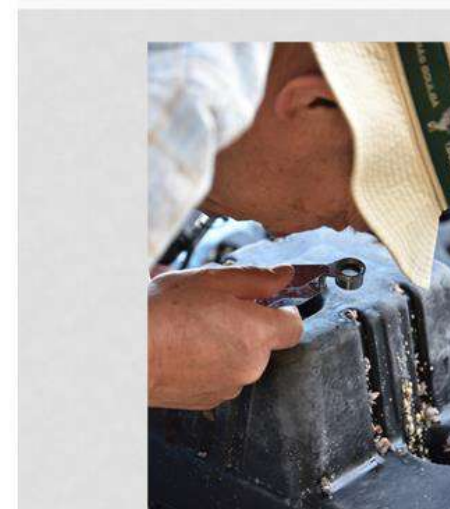
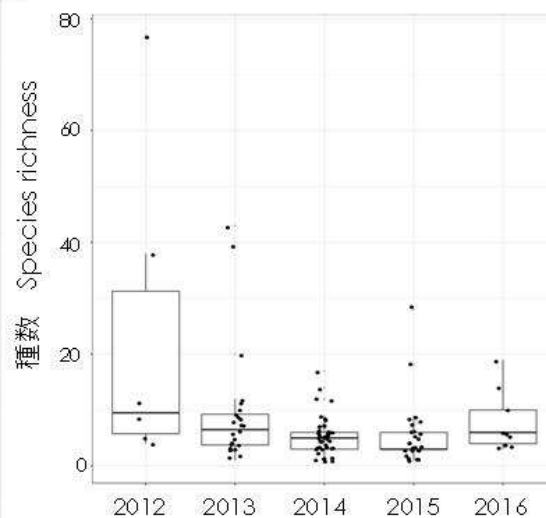
移入過程 THE INVASION PROCESS



移送 TRANSIT - 津波漂流物数 NUMBER OF ITEMS

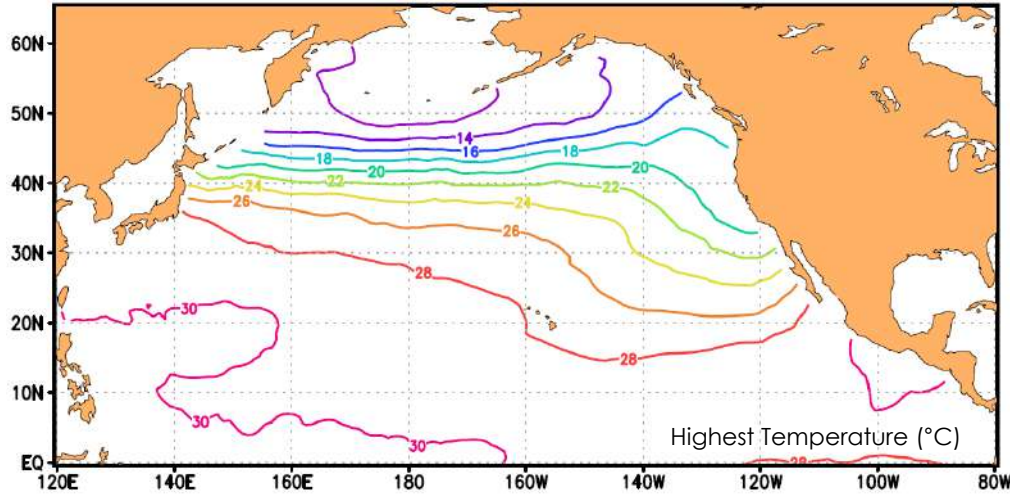


移送 TRANSIT - 漂流物当たりの種数 RICHNESS PER ITEM



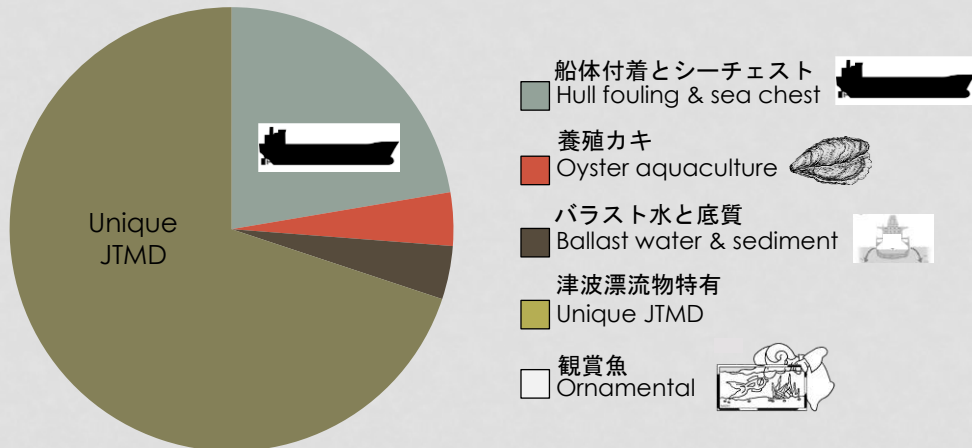
運搬 DELIVERY -環境適合性 ENVIRONMENTAL MATCH

例：北太平洋における年間最高表面海水温度の分布



運び屋 VECTOR	起源 SOURCE	移送 TRANSIT			運搬 DELIVERY	
		供給源量 Source	種数 Richness	数量 Number	生残 Survival	放出 Release
津波漂流物 Tsunami Debris		○	○	○	○	○
船体付着 Hull fouling		○	○	○	○	○
バラスト水 Ballast Water		○	○	○	○	○
観賞魚輸入 Ornamental		○	○	○	○	○
養殖種の輸入 Aquaculture		○	○	○	○	○

運び屋ごとの移入種の重複 SPECIES SHARED WITH OTHER VECTORS



津波漂流物は比較的低リスクと考えられる。 JTMD COMPARATIVELY LOWER RISK

しかしながら、高リスク種の導入可能性から今後の監視が必要である。。。 However... potential to introduce high risk species will require monitoring



WAKAME KELP—INVADER! (*Undaria pinnatifida*)

An edible kelp species native to Japan, *U. pinnatifida* can be highly invasive and disruptive to native kelp ecosystems. In addition to its occurrence on larger tsunami debris, it may recruit in the natural environment on existing docks, pier pilings, or rock in newly disturbed areas. *Undaria* has lobes or finger-like projections on its blade margins and two highly inflated sporophylls at its base. (Keyle Hansen, OSU)

- Size range: blades can grow to 3 m long (see image on page 9 of the long blades of *Undaria pinnatifida* attached to the dock that washed ashore at Agate Beach, Oregon, 13 months after being washed out to sea by the 2011 Japanese tsunami)



NORTHERN PACIFIC SEASTAR—INVADER! (*Asterias amurensis*)

This species of sea star is predominantly light purple in color, and is often seen with purple or red detail on its upper surface. There are numerous small spines with sharp edges on the upper body surface. On the underside of the body, these spines have the groove in which the tube feet are, and pile up at the mouth in a fan-like shape. The underside is a straw-colored yellow in color; it is normally found in shallow water, but it can also be found from the intertidal area through to the subtidal as deep as 200 m. (New Zealand Ministry for Primary Industries)

- Size range: can reach 40 to 50 cm in diameter



PROJECT RESEARCH TEAM

プロジェクト課題担当機関 ~ 15 organizations

- Hatfield Marine Science Center,
Oregon State University
オレゴン州立大学
ハットフィールド海洋科学センター
- Moss Landing Marine Laboratory
モスランディング海洋研究所
- Smithsonian Environmental Research Center
スミソニアン環境研究センター
- International Pacific Research Center (IPRC),
University of Hawaii
ハワイ大学, 国際太平洋研究センター
- Williams College and Mystic Seaport
ウィリアムズ大学&ミスティック海港博物館
- Ehime University
愛媛大学
- Kagoshima University
鹿児島大学
- Kobe University
神戸大学
- Kyushu University
九州大学
- Tokyo University of Science
東京理科大学
- Meteorological Research Institute,
Japan Meteorological Agency
気象研
- Japan Agency for Marine-Earth Science Technology (JAMSTEC)
海洋研究開発機構
- National Institute for Land and Infrastructure Management
国土技術政策総合研究所
- Fisheries Research Agency
水産研究機構
- JANUS
日本エヌ・ユー・エス

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- Sherry Lippiatt, USA
- Stephen Ambagis, USA
- Kristine Davidson, USA
- Nancy Treneman, USA
- Cathryn Murray, Canada





2016.11.10

OUTCOMES AND LEGACY PRODUCTS

- Hawaiian Islands Marine Debris Aerial Imagery Surveys (2015–2016)
- Webcam monitoring of marine/tsunami debris (2014–2017)
- Development of life history database for Japanese Tsunami Marine Debris (JTMD) biota (2015–2016)
- Japan Tsunami Debris species database (2012–2017)
- British Columbia (BC) Coast Marine Debris Aerial Imagery Surveys
- Special Issues of 'Aquatic Invasions' and 'Marine Pollution Bulletin'

