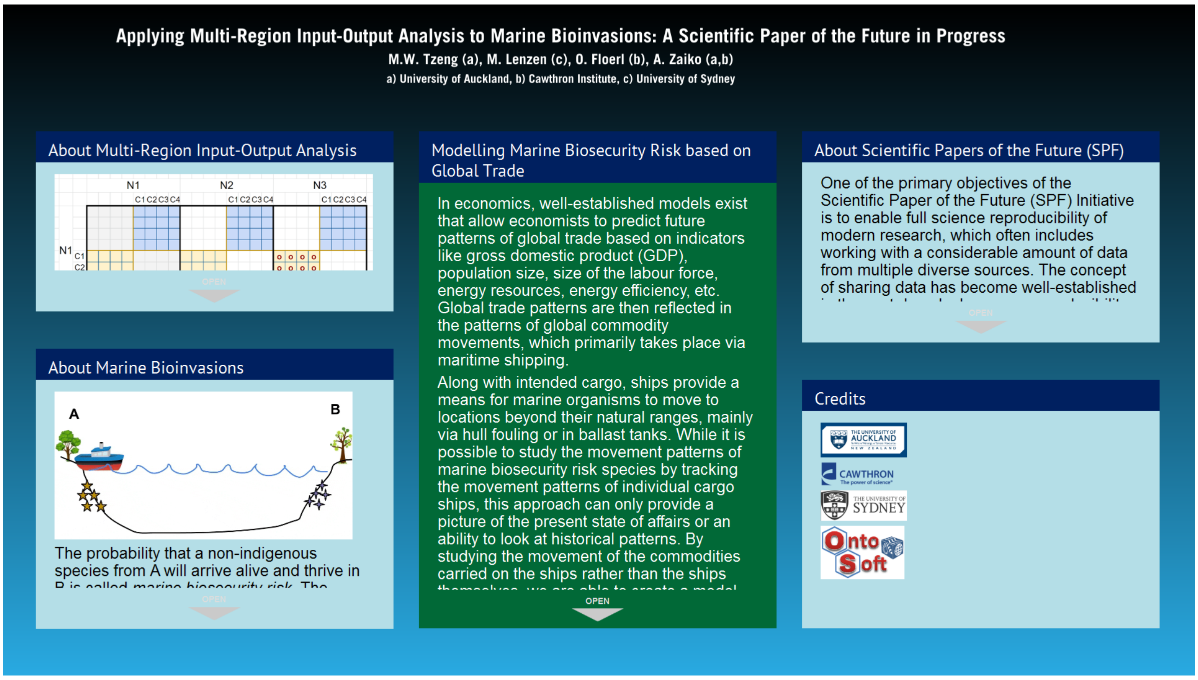
Applying Multi-Region Input-Output Analysis to Marine Bioinvasions: A Scientific Paper of the Future in Progress



M.W. Tzeng (a), M. Lenzen (c), O. Floerl (b), A. Zaiko (a,b)

a) University of Auckland, b) Cawthron Institute, c) University of Sydney

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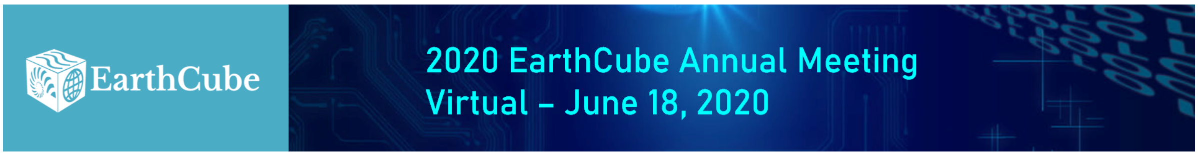
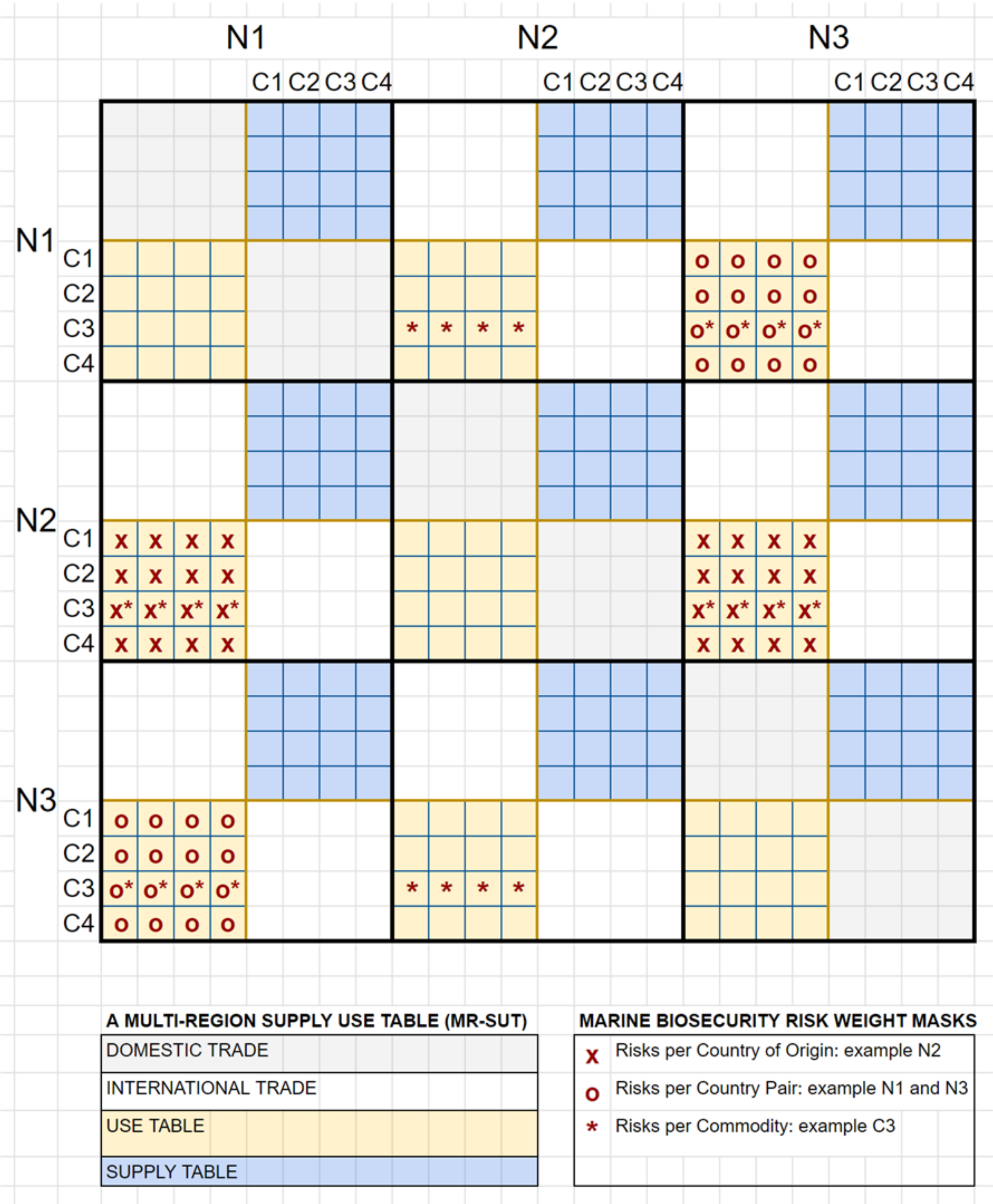


ABOUT MULTI-REGION INPUT-OUTPUT ANALYSIS



In economics, MRIO is used to analyze economic interdependencies between multiple regions. An MRIO table, which holds the raw data of commerce, can have a number of different forms. In our case, we are using a Multi-Region Supply Use Table (MR-SUT).

Our example MR-SUT has three nations that trade four commodities. Each nation is listed in the same order in rows and columns, with each commodity listed in the same order for each nation, resulting in a square block of numbers where the numbers are commodity amounts that are exported from the row nation to be imported by the column nation. In a MR-SUT, the commodities are listed in order twice, and the nation block contains a supply table in the upper right, a use table in lower left, and filler (usually 0s) in the other two quadrants.

Our actual MR-SUT includes trade data between 221 nations for over 6000 commodities. To reduce the size of the table to within computational processing limits, both nations and commodities were grouped into larger aggregates, which resulted in a finalized MR-SUT with 77 nation aggregates and 39 commodity categories, or 6006 rows and columns.

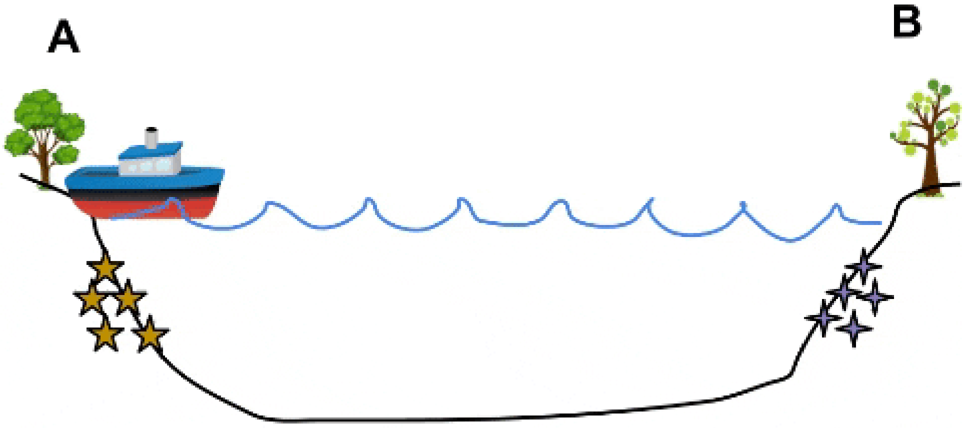
There are three types of marine biosecurity risk weights that can be applied to trade activity between nations:

- Risks from each nation as an origin point
- Risks between each specific pair of nations
- Risks related to specific commodities

Applying these risk weights is a straightforward matter of finding the locations of the correct numbers in the MR-SUT. For nation of origin, these are the use tables in the row for the nation (other than in the domestic nation block). For nation pairs, these are the use tables in the two nation blocks corresponding to the nations of the pair. For specific commodities, it is the corresponding row in every use table in the matrix.

Meanwhile, determining what the risk weights should be is primarily based on concepts from the Model of Marine Bioinvasion.

ABOUT MARINE BIOINVASIONS



The probability that a non-indigenous species from A will arrive alive and thrive in B is called *marine biosecurity risk*. The Model for Marine Bioinvasion (Seebens et al 2013) includes three component probabilities:

- **Probability to be Alien** - is it non-indigenous in B?
- **Probability of Introduction** - is it still alive after the journey from A to B?
- **Probability of Establishment** - can it survive and thrive in B?

Probability to be Alien is based on geographic distance between A and B. The farther away B is from A, the more likely it is that a species from A is not native at B. In our study, Probability to be Alien is based on whether A and B are part of the same marine ecoprovince. Ecoprovinces are one of 62 distinct ecological divisions of the world's coastal areas (Spalding et al 2007).

Probability of Establishment is based on environmental similarity between A and B. Environmental similarity is based on average annual temperature and salinity of the waters within the marine ecoprovinces where A and B are located. The higher the similarity between A and B, the more likely an organism from A will be able to survive conditions at B. Environmental data are from NOAA's World Ocean Atlas (2018).

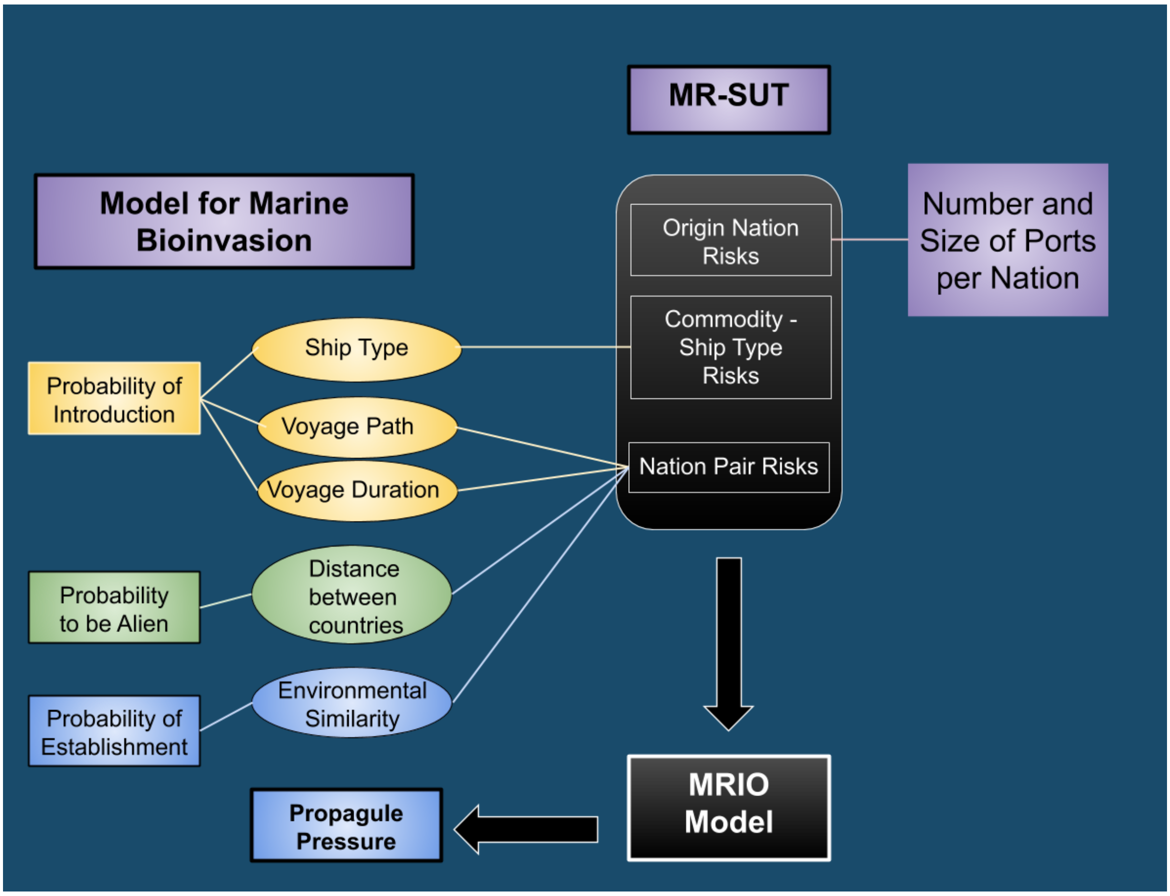
Probability of Introduction is based on three main factors: the voyage duration between A and B, the voyage path between A and B, and the ship type used to transport specific commodities. Each of these affects the mortality rate of potential invasives in transit. Longer voyages mean that food, oxygen (in ballast tanks), etc. will run out, which increases mortality. If the ship's path passes through multiple climate zones, the organisms are exposed to a wider range of environmental conditions, which can increase mortality.

Finally, different types of commodities are transported by different types of ship. For example, tankers transport liquid cargo such as crude oil or fruit juice, while bulk carriers transport bulk solids like coal, ores, or grains. General cargo ships and container ships transport most types of packaged items. Different ship types have different sizes, average speeds, maintenance patterns, configurations of ballast tanks and hull niche areas, and other relevant factors, and therefore different amounts of marine biosecurity risk.

MODELLING MARINE BIOSECURITY RISK BASED ON GLOBAL TRADE

In economics, well-established models exist that allow economists to predict future patterns of global trade based on indicators like gross domestic product (GDP), population size, size of the labour force, energy resources, energy efficiency, etc. Global trade patterns are then reflected in the patterns of global commodity movements, which primarily takes place via maritime shipping.

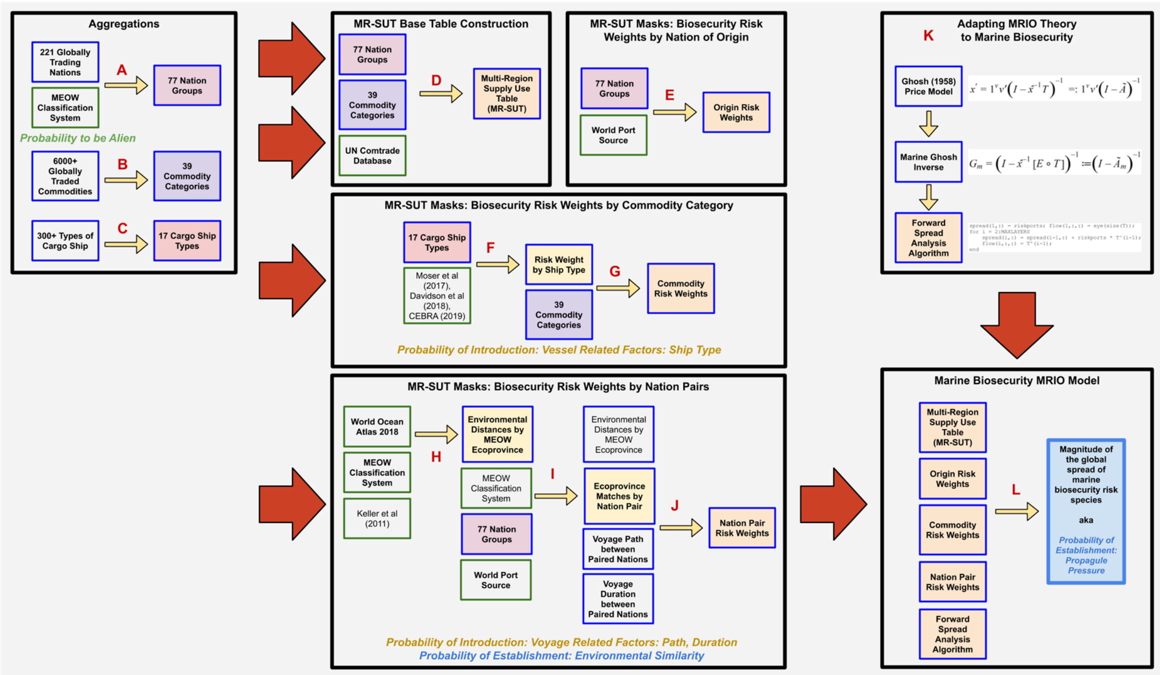
Along with intended cargo, ships provide a means for marine organisms to move to locations beyond their natural ranges, mainly via hull fouling or in ballast tanks. While it is possible to study the movement patterns of marine biosecurity risk species by tracking the movement patterns of individual cargo ships, this approach can only provide a picture of the present state of affairs or an ability to look at historical patterns. By studying the movement of the commodities carried on the ships rather than the ships themselves, we are able to create a model that predicts future movement patterns of marine biosecurity risks based on predictions of future patterns of global trade.



To recap the left sidebars, we have three sets of risk factors derived from the two main input parameters of MRIO (nation groups and commodity categories), and three sets of risk factors based on the three probability components of the Model for Marine Bioinvasion. The above diagram summarizes how they are related to each other in the construction of our model.

Most probability components are related to trade between specific pairs of nations. Probability of Introduction due to ship type is based on the type of commodity being transported; different commodity types are transported by different ship types. Nation origin risks (upper right) are largely based on an estimate of shipping traffic to and from the nation rather than on ecological principles.

Below is a diagram with fuller details, showing the broader picture of the overall workflow of model construction.



A

221 nations were aggregated into 77 nation groups based on the Marine Ecoregions Of the World (MEOW) hierarchical classification system (Spalding et al 2007), which includes 62 ecoprovinces. Nations within the same ecoprovince were aggregated with each other. Nations with no saltwater ports (e.g. landlocked) were aggregated with the nearest nation that has ports, taking into account factors like a) closest coastline, b) geographic barriers like mountains, deserts, etc., c) political relationships, d) closest significantly-sized port (as defined by World Port Source), and e) direction to the top five import/export partners (as defined by the Observatory of Economic Complexity (OEC)).

B

6000+ globally traded commodities were aggregated into 39 categories based on type of commodity and type of ship used to transport it. Broad commodity categories include agriculture/aquaculture/fisheries, forestry, mining, primary form materials, fabricated goods, and passenger services. Other considerations include a) whether the item is solid, liquid, or gas, b) whether the item is perishable, c) use of specialized ships for specialized cargo.

C

300+ different cargo ship types were aggregated into 17 broad categories based on the consensus of numerous past studies of marine biosecurity risk species as transported by ship. The most common ship types in the global fleet are tankers, bulk carriers, general cargo, and container ships.

D

The base MR-SUT table of trade data was constructed with 77 nation groups and 39 commodity categories, using data from UN Comtrade.

E

As a proxy for the amount of shipping traffic passing through each nation group, and therefore the potential of each nation group as an origin point for biosecurity risk species, we counted the total number and size of all ports in each nation group based on port data from World Port Source. Port sizes were assigned a weight: very small and small, medium, large, and very large were each assigned 1, 10, 100, or 1000, respectively. Weights were then added together for all ports to give a total risk weight for the nation group. Weights were scaled between 0 and 1, with 1 set as the maximum risk weight rounded up to the nearest integer.

F

Risk weights were assigned to each ship type based on data from Moser et al (2017), Davidson et al (2018), and CEBRA (2019). Factors taken into account include average wetted surface area per ship, average proportion of hull niche areas (areas with higher or lower water turbulence than the main part of the hull, such as in or around propellers, rudders, sea chests, grates, etc.), average time spent in port, average ship speed while in transit between ports, percentage of ships that discharge ballast water while in port, and amount of ballast water discharged.

G

Risk weights were assigned to each commodity category based on the types of ships most commonly used to transport them. Each commodity category might be transported by multiple ship types.The risk weights per ship type determined in F were added together for a total risk weight per commodity category. Weights were scaled between 0 and 1, with 1 set as the maximum risk weight rounded up to the nearest integer.

H

Environmental distances (Keller et al 2011) are a proxy for the similarity of origin to destination environments based on abiotic factors. These were calculated between every MEOW ecoprovince paired with every other MEOW ecoprovince, using temperature and salinity data from World Ocean Atlas (WOA 2018).

I

Each nation group has saltwater ports in 1-7 ecoprovinces (as determined during nation aggregations (see A)). Ecoprovinces were matched as trading regions between each pair of nation groups, based on whichever ecoprovinces were closest either geographically or via the environmental distances calculated in H, and whether the ecoprovinces had any medium, large, or very large ports.

J

Matched ecoprovinces were used to determine likely voyage path and duration between nation pairs. Along with the initial environmental distances calculated in H, each of these were assigned risk weights, which were then added together for a final risk weight per nation pair.

K

Ghosh(1958) formulated a fundamental input-output relationship for price shocks repercussing downstream in a supply-push economy. We have adapted the Ghosh price model to instead trace the downstream fate of marine biosecurity risks travelling in vessels carrying goods along international trade routes. The resulting forward spread analysis can trace the spread of marine biosecurity risks over trade routes with multiple shipping stops, from any number of origin points.

L

Putting it all together: The input parameters for the marine biosecurity MRIO model are the base MR-SUT table and the various types of risk weights. The forward spread analysis algorithm calculates the magnitude of the global spread of marine biosecurity risk species over multiple shipping stops with various origin points.

ABOUT SCIENTIFIC PAPERS OF THE FUTURE (SPF)

One of the primary objectives of the Scientific Paper of the Future (SPF) Initiative (https://www.scientificpaperofthefuture.org/) is to enable full science reproducibility of modern research, which often includes working with a considerable amount of data from multiple diverse sources. The concept of sharing data has become well-established in the past decade; however, reproducibility also requires sharing the details of how the data were processed, organized, manipulated, analyzed, etc. before it becomes published results in a peer-reviewed journal article, usually beyond the limits of what can be included in a traditional methods section. According to best practices for a fully reproducible science paper (Gil et al 2016), SPFs should include:

Data and Software

- Openly shared
- Unique identifiers
- Licensed
- Documented (metadata)

Workflow

- Provenance of specific dataset
- Methods of data analysis

Author(s)

- Unique identifiers

In our poster, we begin the process of compiling an SPF from an interdisciplinary and computationally complex study in progress: a model of the global movement patterns of marine biosecurity risk species based on current or future patterns of global trade. Our eventual goal is to produce full documentation for how our model was constructed, including input data sources, intermediate data products, all software used, and workflow. This documentation will be published either as a technical report which can be cited by our planned series of science papers, or as supplemental information linked to the first paper.

CREDITS

CV

Mimi Tzeng

PhD student, University of Auckland

ORCID # 0000-0001-9396-3217

Manfred Lenzen

Professor, University of Sydney

ORCID # 0000 0002 0828 5288

Oliver Floerl

Biosecurity Team Leader, Cawthron Institute

ORCID #

Anastasija Zaiko

Marine Scientist, Cawthron Institute

Senior Lecturer, University of Auckland

ORCID # 0000-0003-4037-1861

ABSTRACT

The Scientific Paper of the Future (SPF) concept, initiated by the EarthCube OntoSoft Funded Project, encourages scientists to publish not only peer-reviewed journal articles, but also all associated data, software (data processing scripts), and computational workflows, in order to enable full science reproducibility. While the SPF concept was originally aimed at geoscientists, it can also be applied to interdisciplinary projects such as between ecology, economics, and maritime shipping.

Multi-region input-output (MRIO) analysis is a method from economics for analyzing economic interdependencies between different regional entities. Entities can be countries, regions within a country, or groups of countries. MRIO can also be used to analyze other types of interdependencies, such as the environmental impact of one region's activities on another.

For this project, we use MRIO to analyze the global spread of marine non-indigenous species via cargo ships. Over 90% of global trade occurs by maritime shipping. Along with intended cargo, ships provide a means for marine organisms to move to locations beyond their natural ranges, mainly via hull fouling or in ballast tanks. These species can have harmful ecological and economic impacts at their destinations. By using MRIO to follow the imports and exports of commodities between countries, we can deduce the magnitude of seaborne trade connections based on physical volume of commodity traded, and therefore the magnitude and geographic distribution of marine biosecurity risk.

MRIO model construction involved incorporating a diversity of data types from ecology, economics, and shipping, and has turned out to be a surprisingly complex endeavor. My poster will demonstrate the principles of an SPF by providing a diagram of the computational workflow involved in the model's construction, including an explanation for each dataset incorporated into the model's input parameters and each piece of software written to process the data and assemble and run the model.

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World Port Source: http://www.worldportsource.com/countries.php (http://www.worldportsource.com/countries.php)