Portfolio-Scale Infrastructure Analysis Using AIS

Coastal Navigation Portfolio Management

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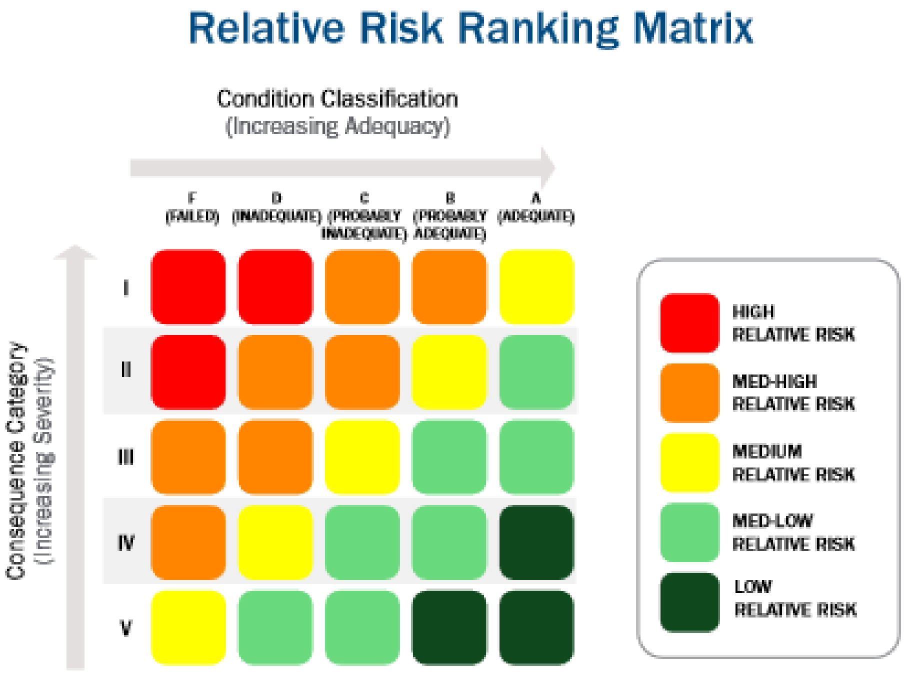
Coastal Navigation Portfolio Management

Advance objective, quantitative, and systems-based approaches to management of the Corps' large coastal navigation portfolio of projects.

- Statements of Need:
  - 2017-N-52 Further Development of CPT and AIS software products
  - 2016-N-14 Long-term modeling of coastal structure functionality
  - 2015-N-15 - Integration of national and local monitoring datasets to support navigation and operations projects
  - 2015-N-34 - Incorporating methods to evaluate length of navigation channel required for safe and efficient travel of two way traffic in ship simulations
  - 2015-N-38 - AIS investigation of Dredge Behavior
  - 2015-N-40 - Reducing the need for dredging

Research Goals

- Augment subjective, qualitative navigation structure performance metric (OCA), and proxy project maintenance prioritization metrics (tonnage, value).
- Cast structure performance in terms of vessel activity for navigation structures.
- Formulate management metrics at “portfolio scale”.



Why this matters…

USACE has awarded contracts valued at ~$47M per year since 2007 on Jetty maintenance, repair, and construction.

The average maintained HMTF project (~521) costs $~1.9M annually.
There are ~541 HMTF projects that are not maintained.

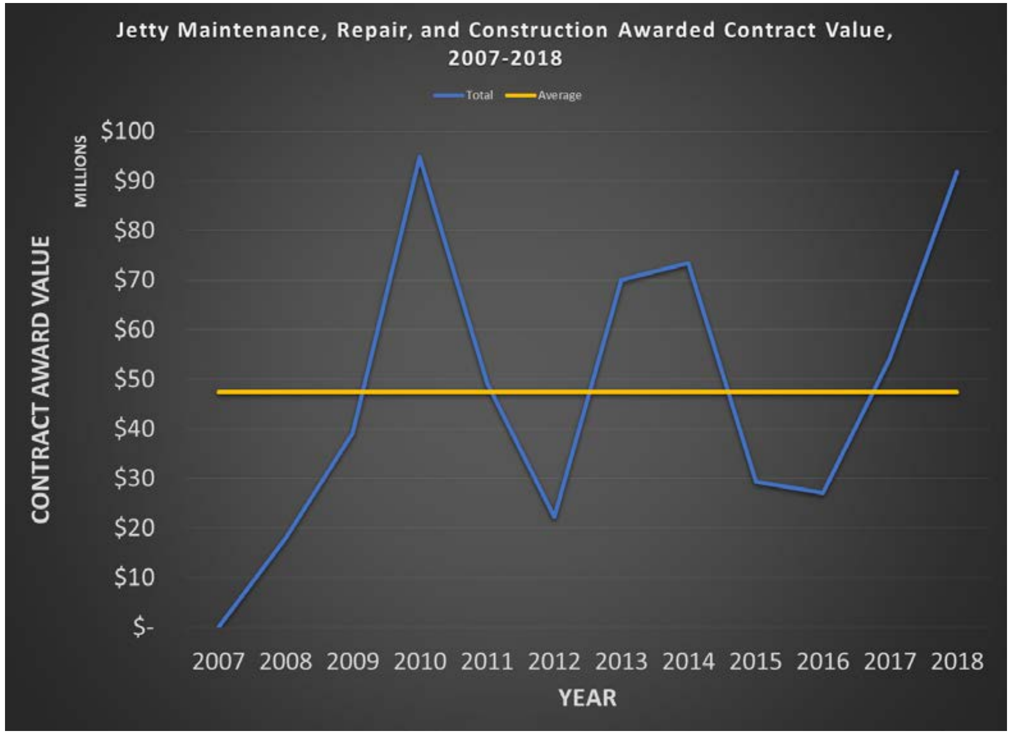
10-year coastal structure expenditure ≈ 24 HMTF projects.

MCR Repair costs ($257M):
- **North Jetty: $79,797,000**
- **South Jetty: $146,884,000**
- **Jetty A: $30,520,000**

Project BCR: 1.1

http://cdm16021.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/3/filename/4.pdf

MCR Repair Costs ≈ 25% annual USACE dredging budget.



Structure Functional Assessment

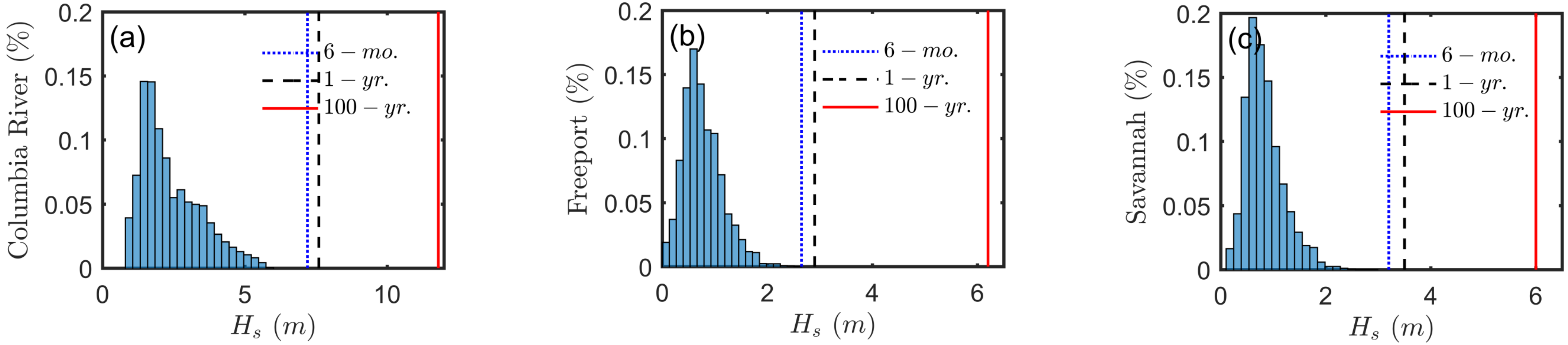
- Structure functional condition is tied to vessel navigability, O&M dredging increase.
- “Vessel navigability” measurement is anecdotal or expensive to measure directly
- O&M dredging increase over background marginally related to structure function,
- O&M dredging increase over background relates to bathymetric elevation, not the ability of vessels to transit.
- Other research has shown that vessels:
  - Frequently call at drafts below design vessel draft
  - Frequently call at water levels above design water level.
- Currently no practice for quantifying the vessel operating functions described in FCR

Level of Functionality	TABLE F-10 Coastal Navigation Structures Functional Condition Rating (FCR) Table
Full -- A	No notable impact, project performing as designed.
Sufficient – B	(1) Infrequent or periodic limitations on navigability, or (2) minor/periodic increases in dredge quantity
Reduced -- C	(1) Less than 10% of the time, design vessels cannot navigate or operate within authorized limits; (2) O&M dredging requirements in the Entrance and Bar Channel have increased less than 10%, as compared to the long-term average annual rate.
Severely Degraded -- D	(1) 10-20% of the time, design vessels cannot navigate or operate within authorized limits; (2) O&M dredging requirements in the Entrance and Bar Channel have increased 10-20%, as compared to the long-term average annual rate.
Completely Degraded -- F	(1)-20-40% of the time, design vessels cannot navigate or operate within authorized limits; (2) O&M dredging requirements in the Entrance and Bar Channel have 20-40%, as compared to the long-term average annual rate.

Previous Effort

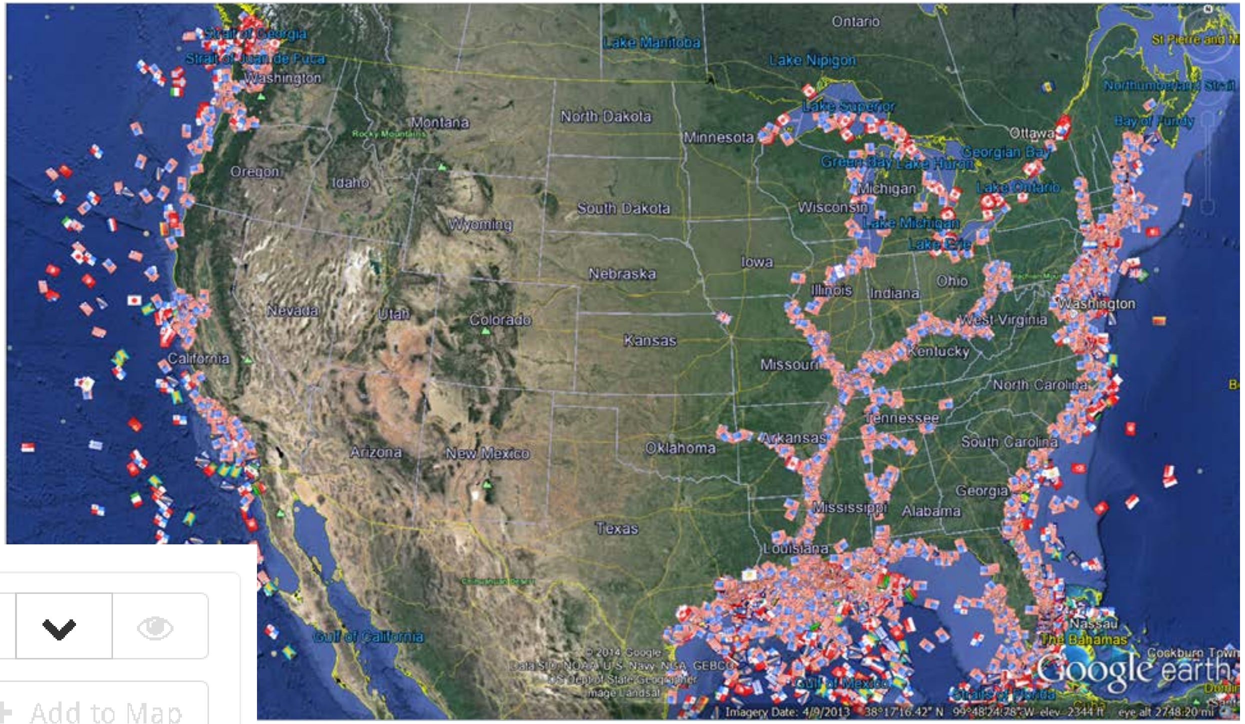
- Quantifying sheltering effects on vessels using AIS data, 2012-2014:
  - Mouth of Columbia River, OR; Savannah, GA; Freeport, TX
  - ~10,000 historical vessel transit observations
  - Findings indicate:
    - During larger wave conditions, the vessels experienced signficantly less heading-course deviation when within/behind the structure - i.e., improved handling when sheltered by jetties.
    - Vessel maximum wave height operating condition was below the 6-month return period wave height, i.e. structures provide no direct benefit to vessels during more energetic conditions.

Wave heights during vessel transits, 2012-2014



Marine Cadastre

- Nationwide AIS 1-minute sampling
- Available 2009-2017
- Marinecadastre.gov



2009 - 2017 National AIS at 1 Minute Intervals

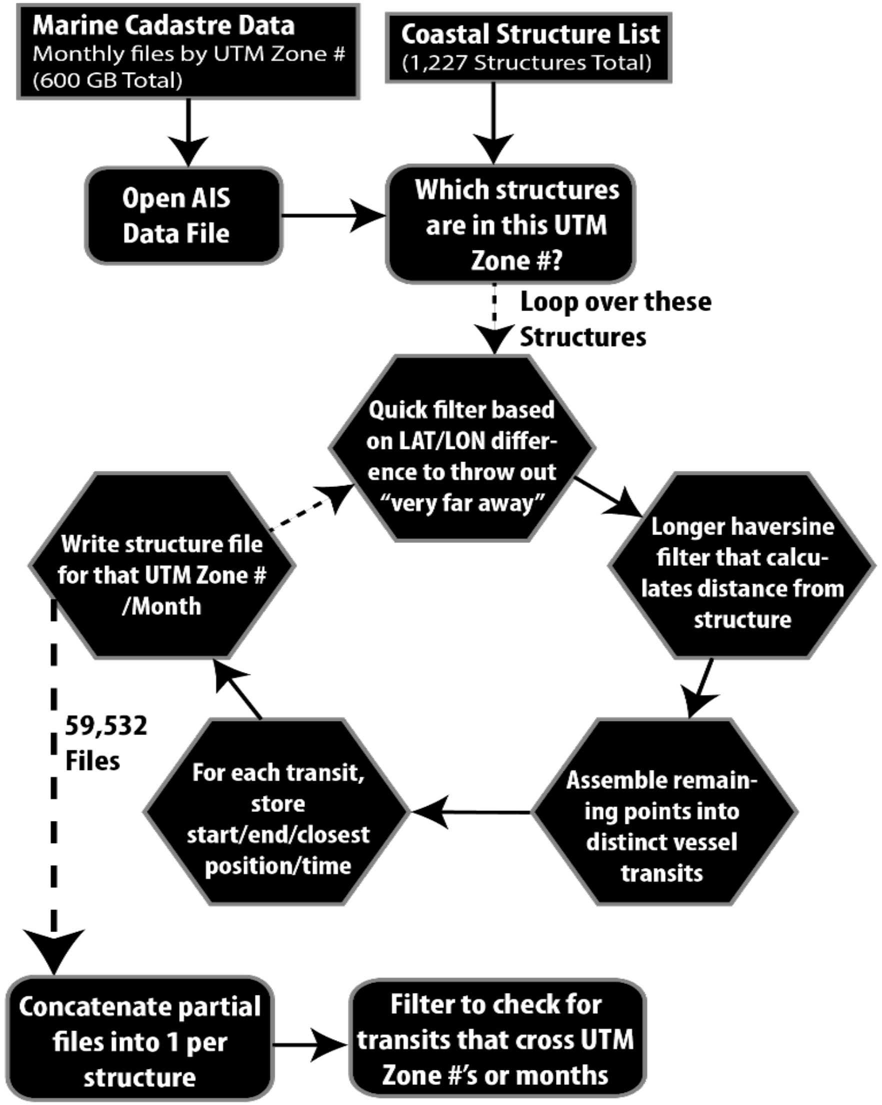
MarineCadastre.gov

+ Add to Map

Automatic Identification System (AIS) data are information collected by the U.S. Coast Guard to monitor real-time vessel information to improve navigation safety. Data such as ship name, purpose, course, and speed are acquired 24 hours per day primarily in coastal U.S. waters. However, the data sets featured on this website are the 2009 to 2017 archived AIS data sets intended to be used by the ocean planning community to better understand vessel traffic patterns. These data are provided for analysis in desktop GIS software. For more information, visit the Nationwide Automatic Identification System website.

Distributed AIS-derived Inlet Structure Metrics

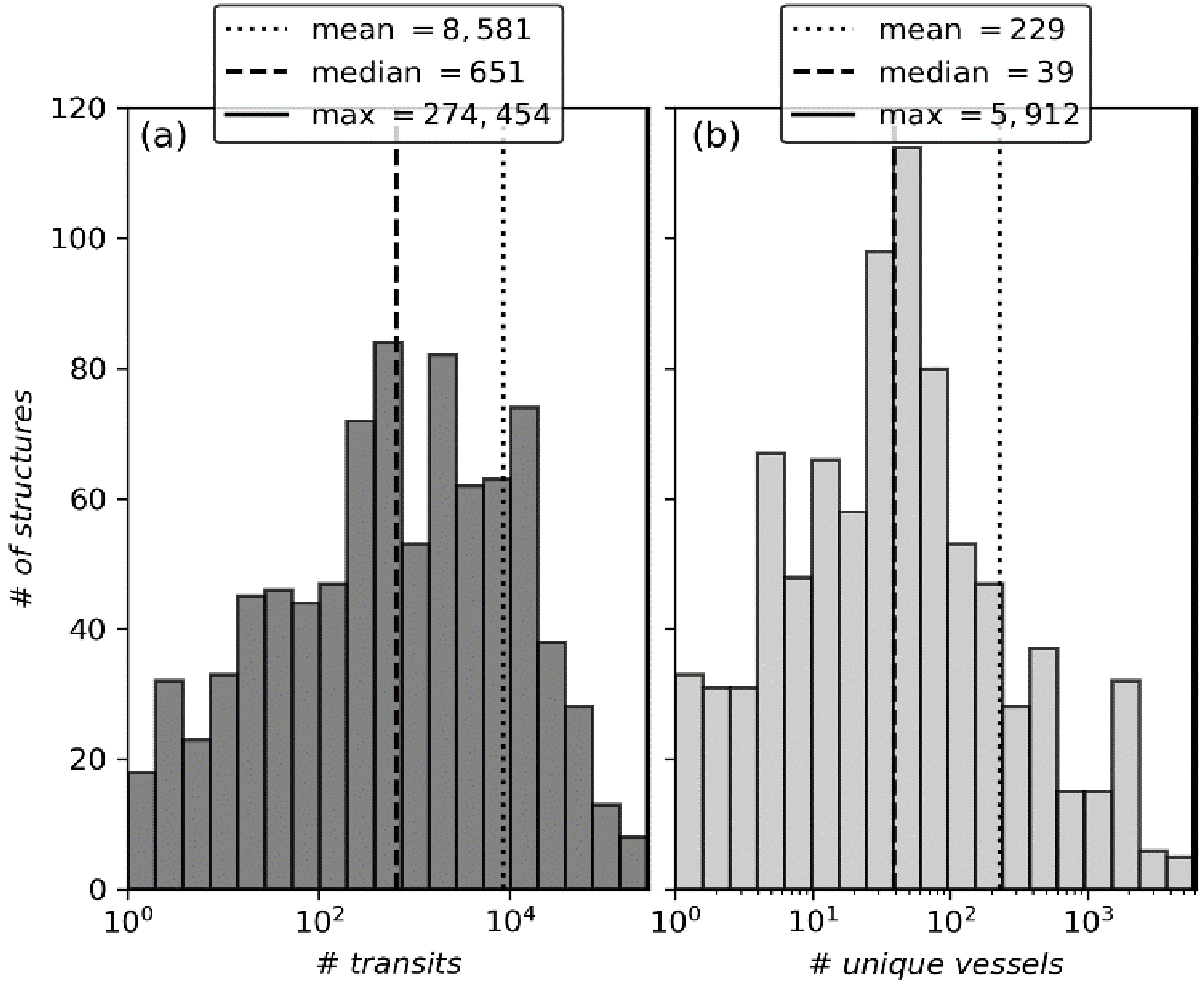
- Metrics are easy:
  - Vessel transit count
  - Number of unique vessels
  - Transits/unique vessel
  - Vessel closest point of approach
  - Seasonal time-series decomposition
  - Information Entropy
- Portfolio scale analysis requires parallel approach
  - Historical vessel data (~600GB)
  - Structure portfolio (~1,200 structures)



Results

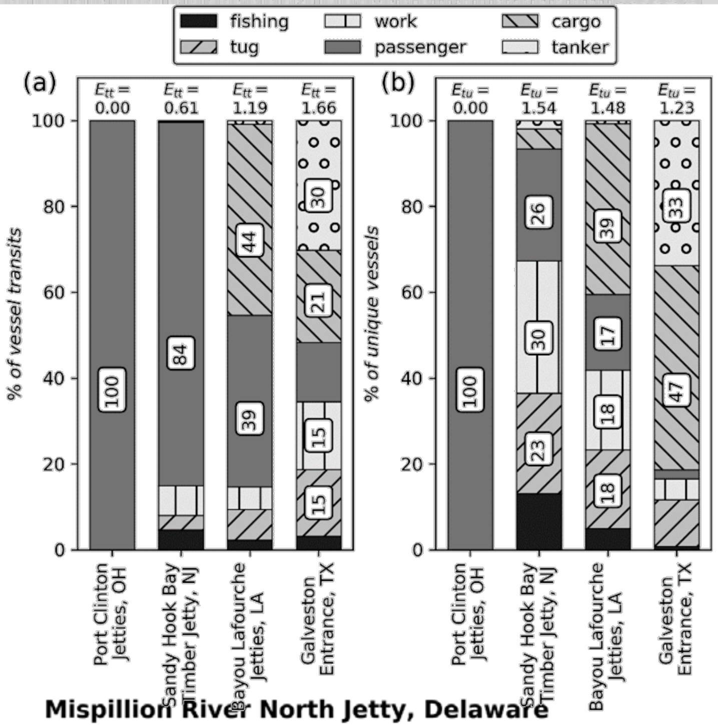
- **We considered:**
  - **6 years of data (2009-2014)**
  - **865 navigation structures**
  - **8M vessel transits (+ i.d.)**

Ship and Cargo Type Code	Description
30	Fishing
31, 32	Towing (ahead or alongside, astern)
52	Tugs or workboats
6X*+	Passenger ships ≥ 100 gross tons
7X*	Cargo (freight) ships or integrated tub barge (ITB) vessels
8X*	Tankers or integrated tug tank barge vessels
* where X indicates digits 0-9, representing all vessels in this class.	
+ passenger vessels ≤ 100 gross tons and high speed craft coded as 4X were excluded	

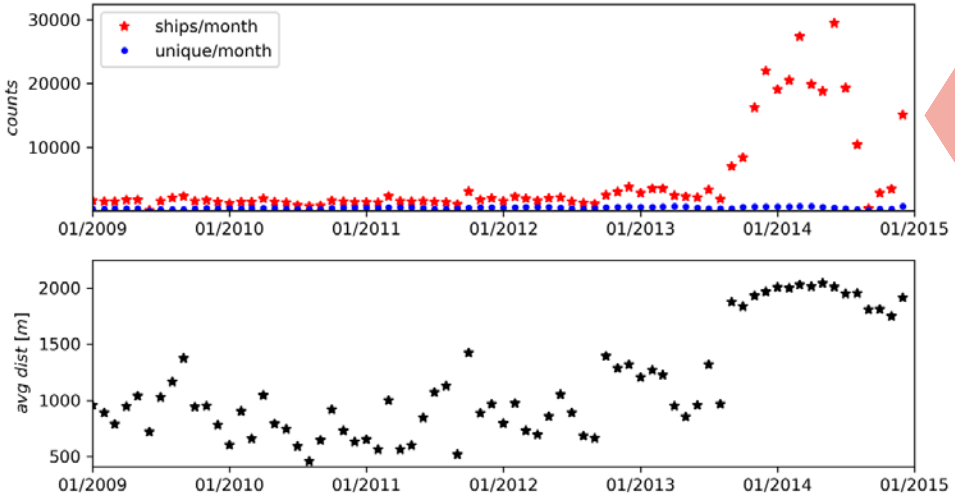


How do we find interesting structures?

- Information Entropy
  - Entropy = ∑ [*P*(*k*) * *ln*(*P*(*k*))]
  - Maximum entropy: Even distribution across categories
  - Minimum entropy: Distribution focused in fewer categories
- Average trip per user = Total/Unique
  - Indicates frequent trips relative to the user base



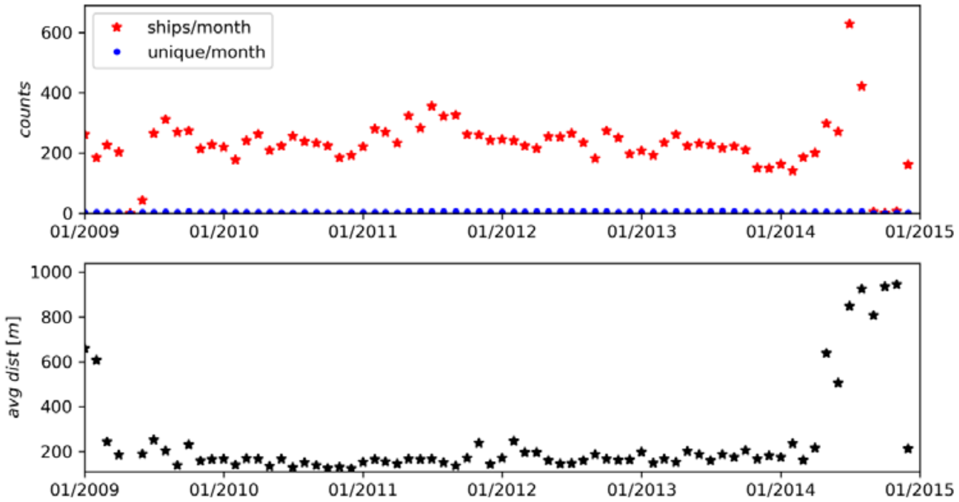
Port Everglades Harbor North Jetty, Florida



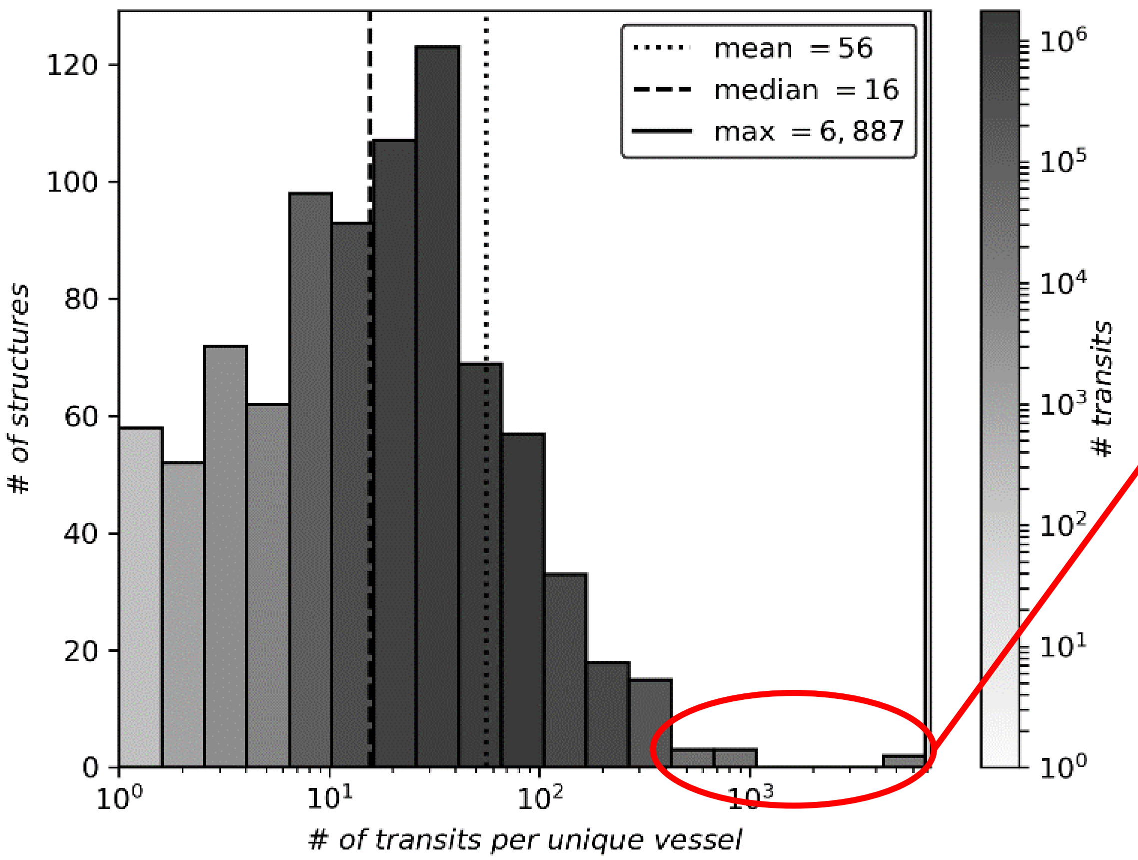
Yearly
Entropy = 1.328
Total/Unique = 47.5

Total/Unique =
16366/28 = 584.5

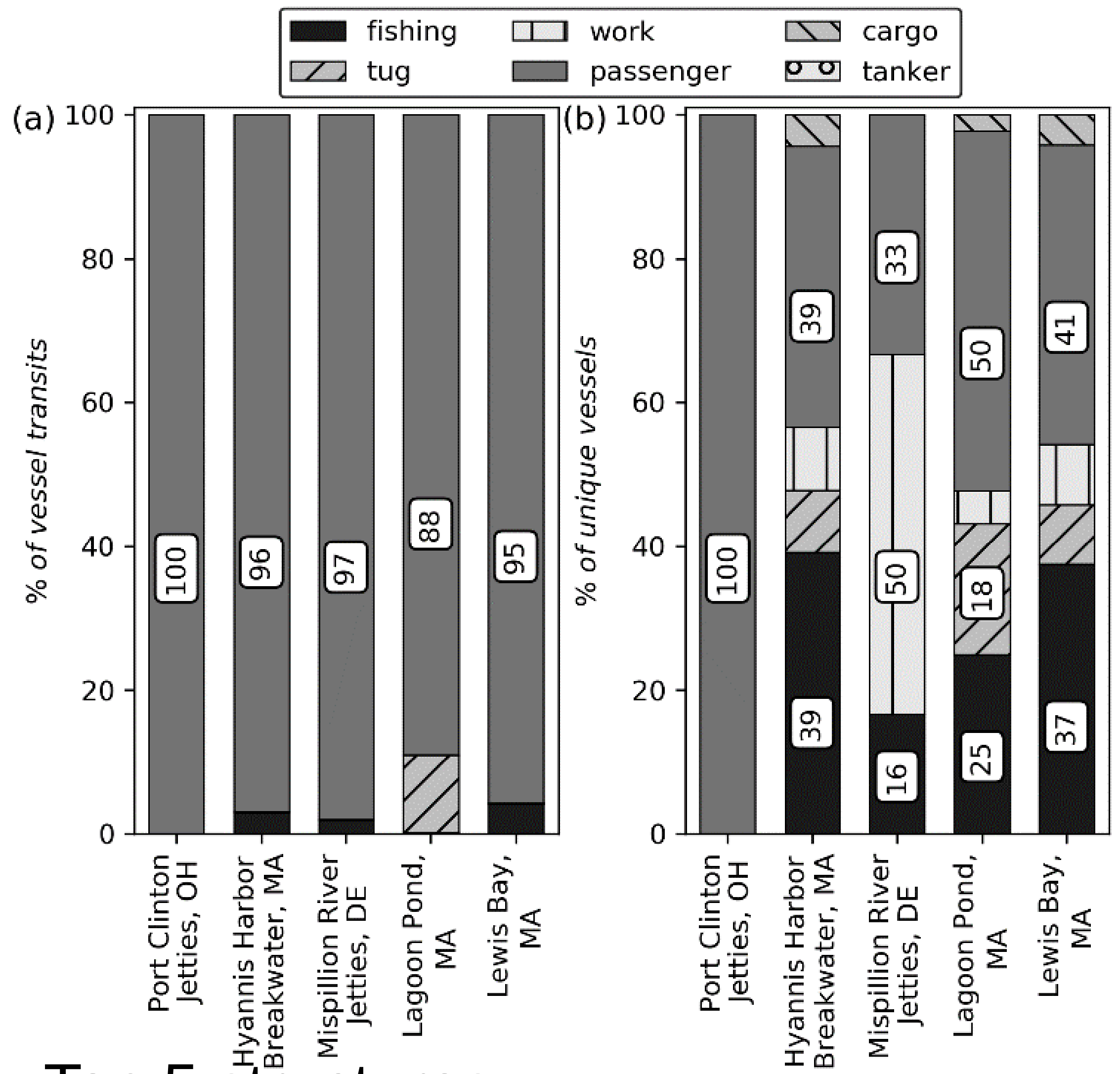
Mispillion River North Jetty, Delaware



Transits/Unique Vessel

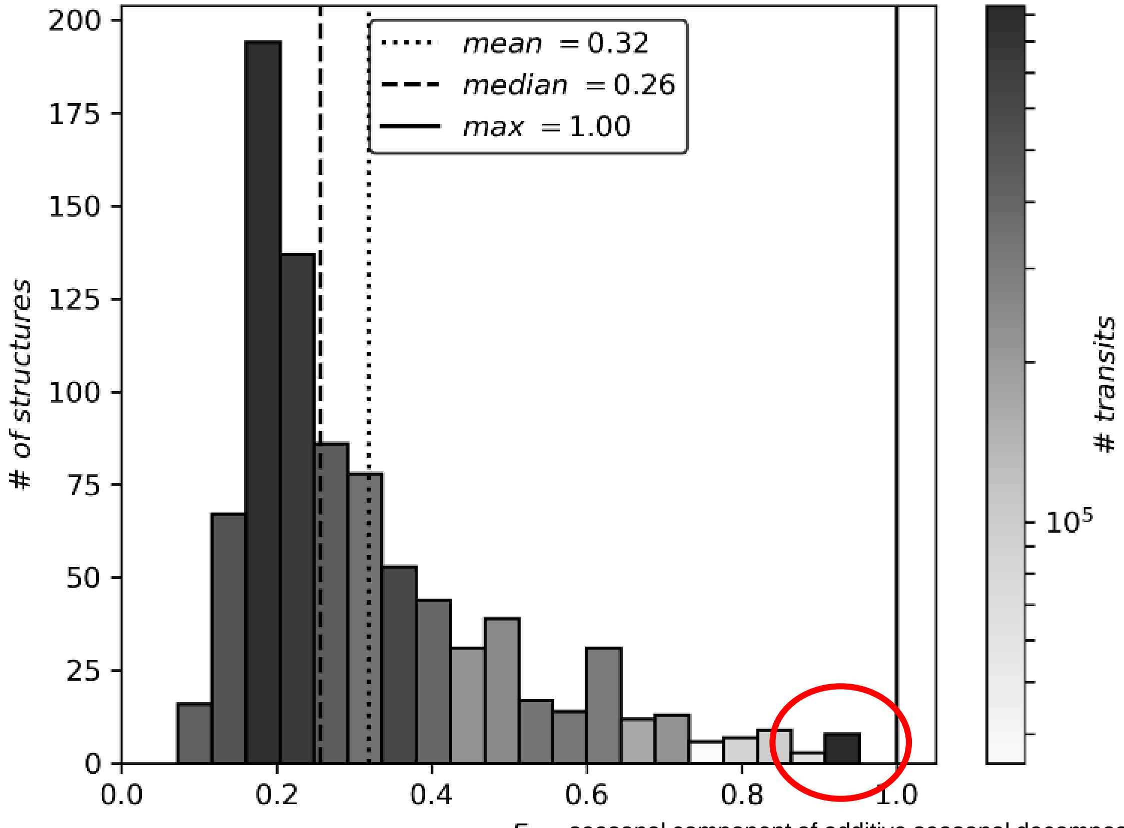


Transits per unique vessel

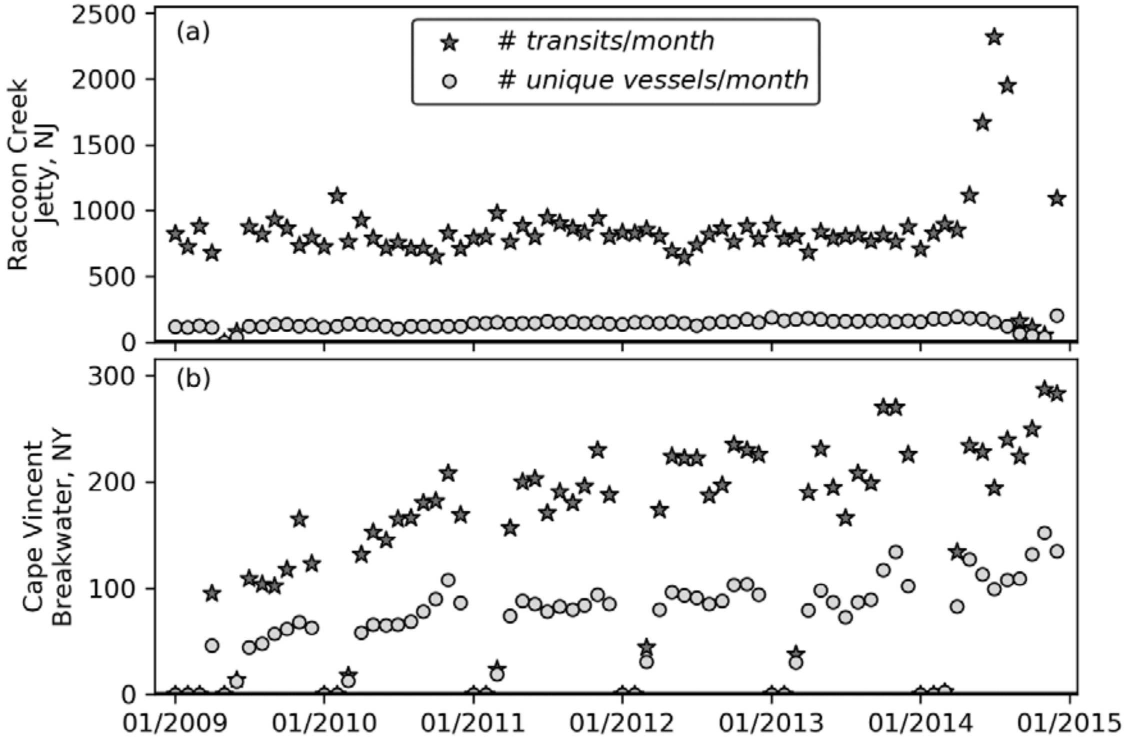


Top 5 structures:
(a) % transits by vessel type and
(b) % unique vessel type

Seasonality



F_{st} - seasonal component of additive seasonal decomposition.

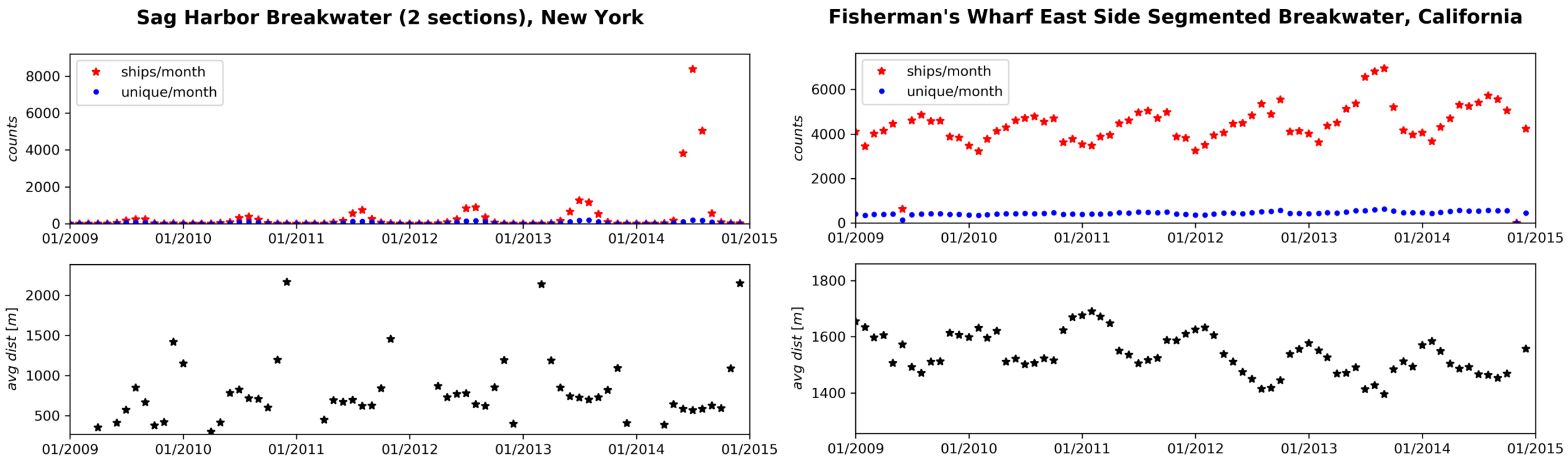


Low vs. High Seasonality

Vessel Transit Seasonality:
A few very seasonal projects representing many transits

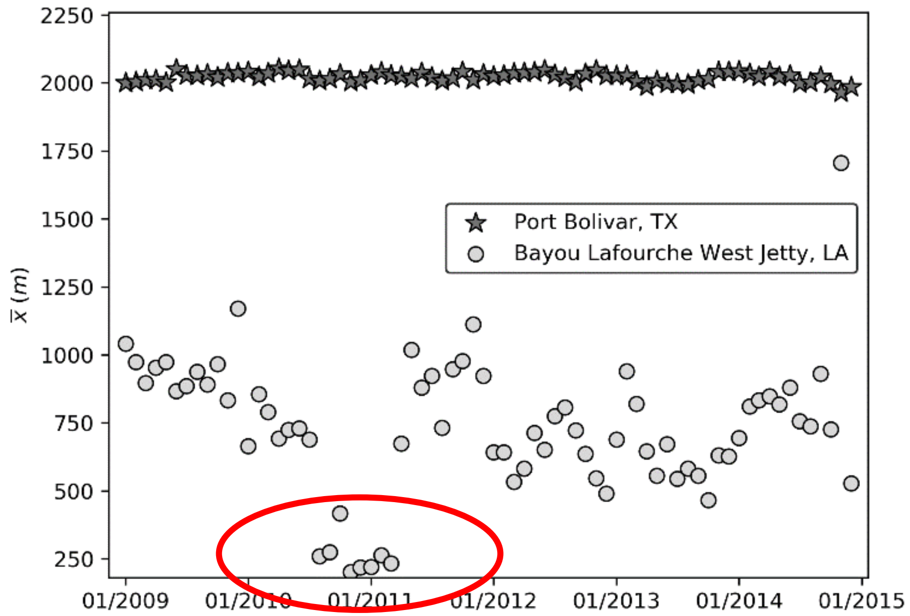
Seasonality

- Peak structure loading (wave activity) occurs outside of peak user activity.
- It’s possible that seasonality is related to different maintenance funding needs.

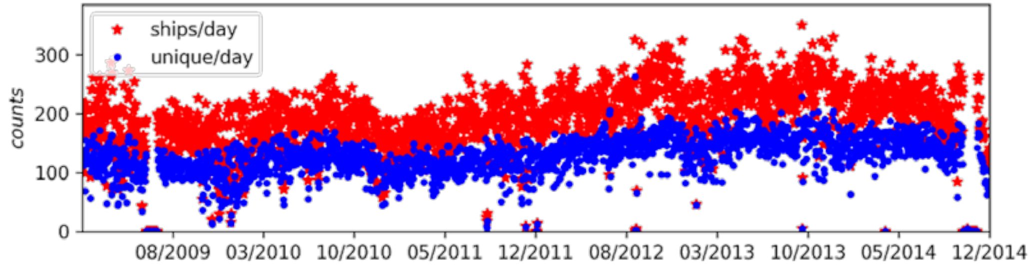


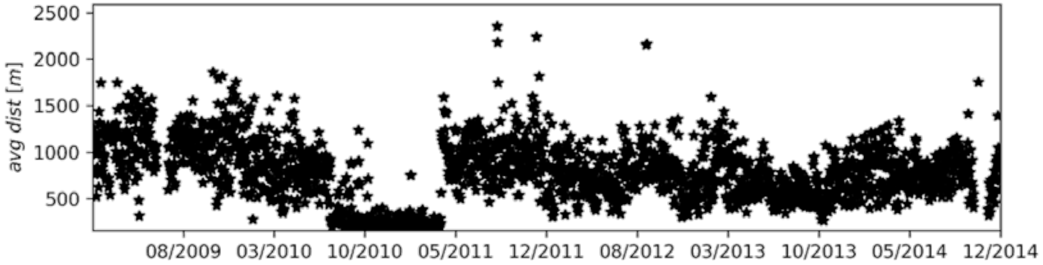
Informing Operations

- Structures demonstrated different spatial behaviors over time.
  - Bayou Lafourche shows an interesting period where vessel closest point of approach reduced to ~25% of the average for ~8 months. Why?
  - Possibly related to BP Horizon oil spill 4/20/10-7/16/10
  - Port Fourchon services 90% GoM OSV fleet.
- This information is available at scale and can be tied back to any spatio-temporal dataset of interest, creating opportunities to answer specific District questions.



Bayou Lafourche West Jetty, Louisiana





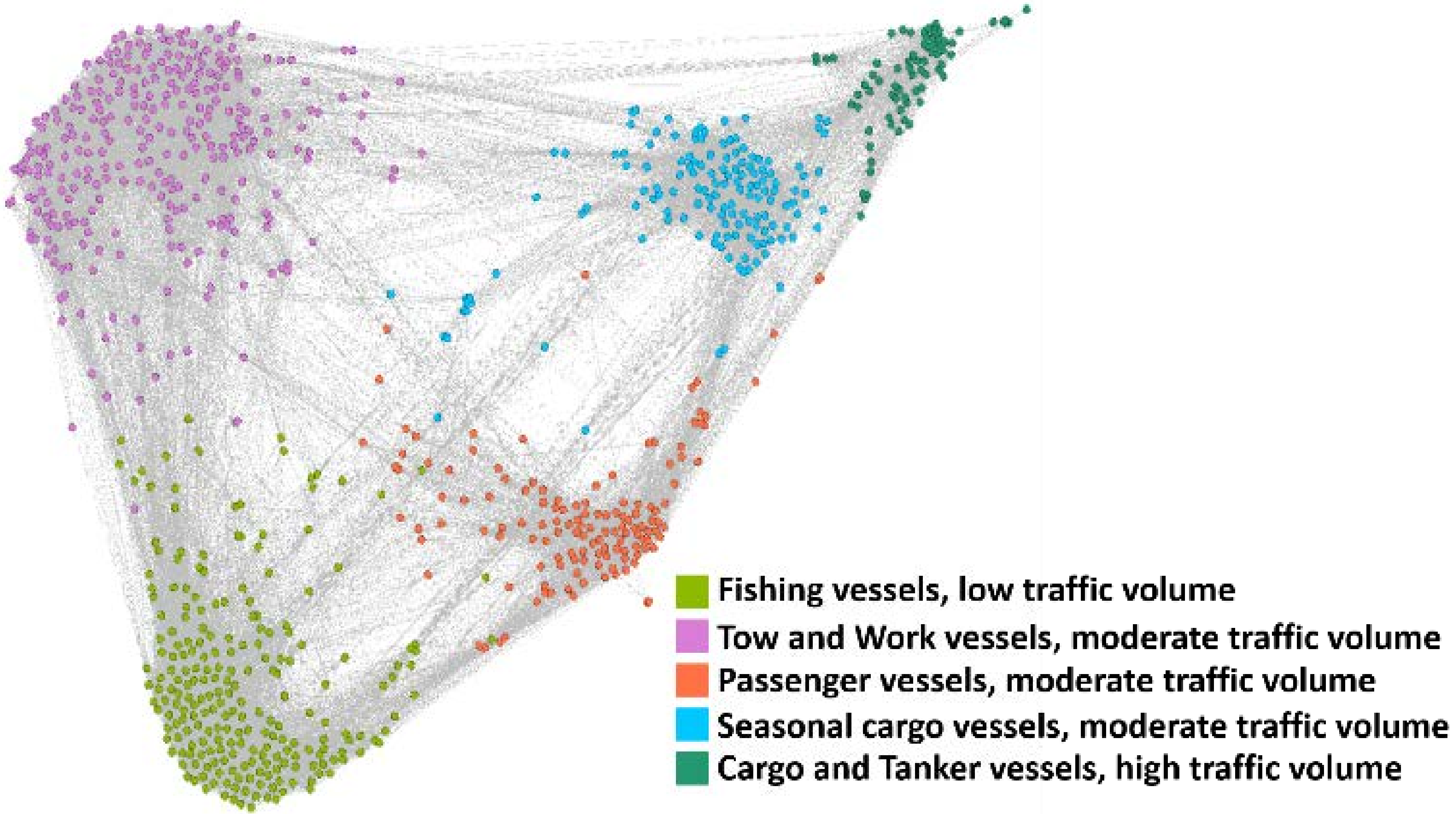
Putting it all together: feature vectors

- r2Cnts – The coefficient of determination for overall fit of the time series decomposition model of vessel traffic at each structure based on the total number of observed vessel transits.
- FsCnts – The coefficient of determination for the seasonal component of the time series decomposition model of vessel traffic at each structure based on the total number of observed vessel transits, F_{st}
- r2Unq – The coefficient of determination for overall fit of the time series decomposition model of vessel traffic at each structure based on the total number of unique vessels observed.
- FsUnq – The coefficient of determination for the seasonal component of the time series decomposition model of vessel traffic at each structure based on the total number of unique vessels observed.
- unq – The total number of unique vessels observed at each structure.
- count – The total number of individual transits observed at each structure.
- trips_per_unq – The average number of individual transits observed for unique vessels at each structure.
- avg_dist – For each structure coordinate pair, x is the distance between the coordinates and the AIS broadcast location nearest the structure for each observed transit within the search radius. Avg_dist, $\bar{x}$, is the average of these CPA distances for each structure.
- fish_% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 30.
- fishUnq_% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 30.
- tow_% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 31 or 32.
- towUnq% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 31 or 32.
- work_% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 52.
- workUnq_% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 52.
- passenger_% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 60 through 69.
- passengerUnq_% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 60 through 69.
- cargo_% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 70 through 79.
- cargoUnq_% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 70 through 79.
- tanker% – The fraction of the total number of observed vessel transits at each structure with ship and cargo type code 80 through 89.
- tankerUnq_% – The fraction of the total number of unique vessels observed at each structure with ship and cargo type code 80 through 89.

Clustering Features: Management Groups

- Each Structure gets a score for 20 features
  - Each score is standardized: $-1 \leq x \leq 1$
- Pearson Correlation of Navigation Structures (865x865 dense matrix)
  - How similar are structures?
- r-Neighborhood pruning (865x865 sparse matrix)
  - Which structures show correlation exceeding 90%?
  - We don’t care about anti-correlation.
- Label Propagation Community Detection Algorithm
  - Cordasco, G., & Gargano, L. 2010

Detected Communities



Conclusions

- AIS-derived traffic metrics quantitatively relate portfolio assets (structures) to use (vessels)
- Feature vectors can be customized to describe relevant metrics. We could add:
  - Wave loading/design height
  - Historical maintenance cost or effort
  - Transit vs. wave height timing coincidence
- AIS-derived metrics facilitate rational allocation of scarce operating funds
- Community detection can facilitate group-wise management
- Parallel computing approach facilitates “portfolio scale” analysis
- Development of parallel computing capability in this space strategically positions CIRP within the vessel computational analysis space
- Next steps, i.e computation of 4-d vessel clearance, builds on this work.

Benefits

- Working at scale strategically positions CNPM to explore other AIS-derived portfolio-wide metrics
  - 4-D around-ship clearance – FY 19 goal
  - Vessel-based infrastructure classification
  - Large scale quantification of navigation risk
- A variety of alternative datasets can be swapped in for structure dataset
  - Ports
  - Habitat
  - Population centers
- Nationwide answers – navigation projects don't exist in a vacuum.

Bonus Images

- These images come from the draft JP on the analysis of vessel activity near USACE navigation structures.
- Over 8M vessel transits of vessels with known identity were documented at 865 navigation structures from 2009-2014.
- In total, over 21M vessel transits were observed near 1,049 structures for the same period.

Mouth of the Columbia River, Jetty “A”

USACE Deep Draft and Shallow Draft Navigation Projects		5-Year Avg.	5-Year Avg.	5-Year Avg.	
Rank (tonnage)		2001-2005	2001-2005	2001-2006	
	Project - Civil Works Identification System Number	Expenditures	Tonnage	$/Ton	% of Total Expenditures
22	COLUMBIA RIVER AT MOUTH, OR AND WA-003600	$ 9,792,281	37,564,544	0.26068	1.524%

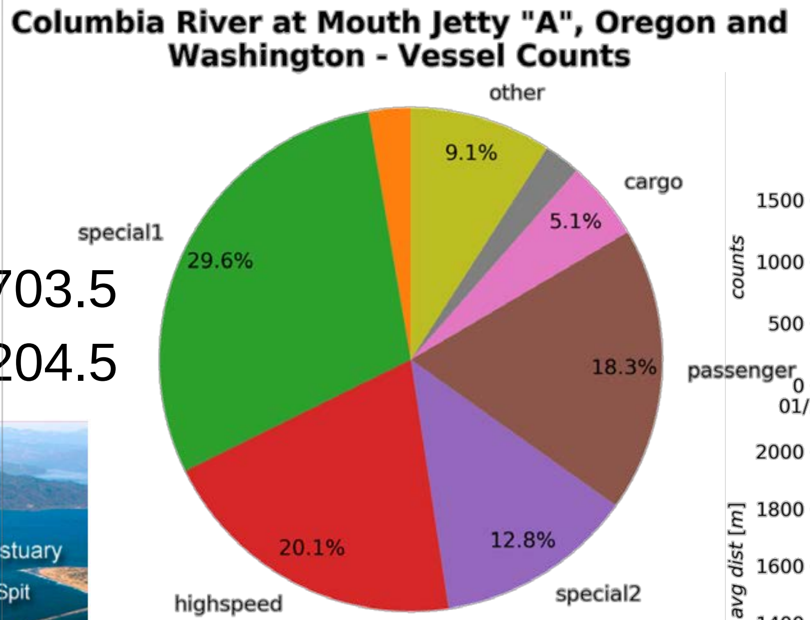
Rank: 99th out of 1080

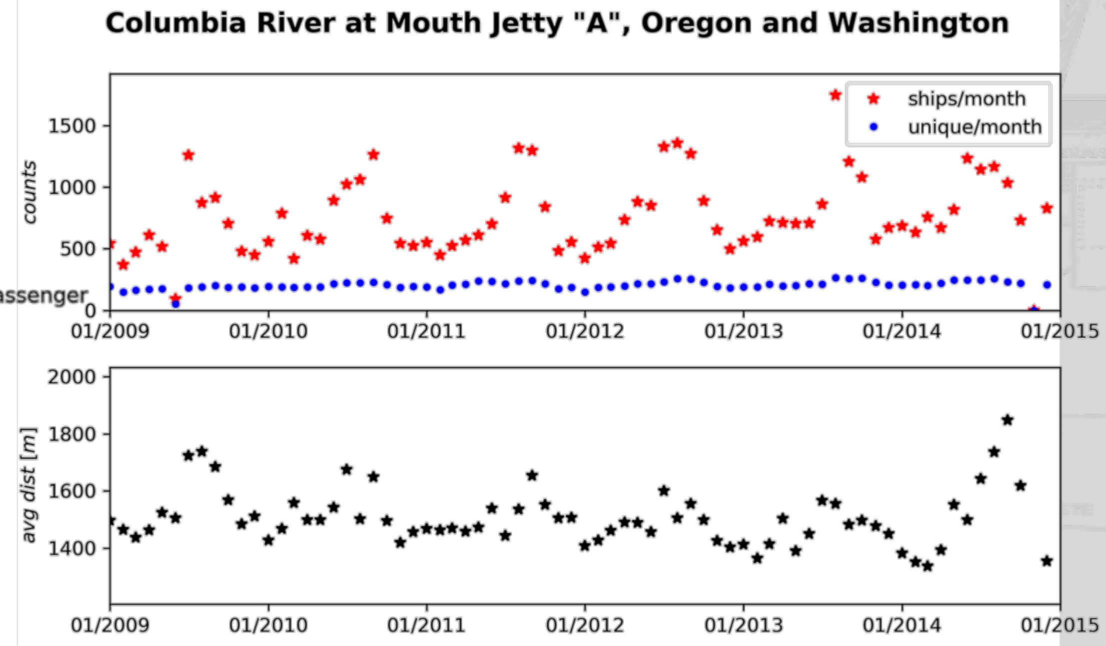
Counts: 54,849

Unique Counts: 4,760

Median Counts in 1 Month – 703.5

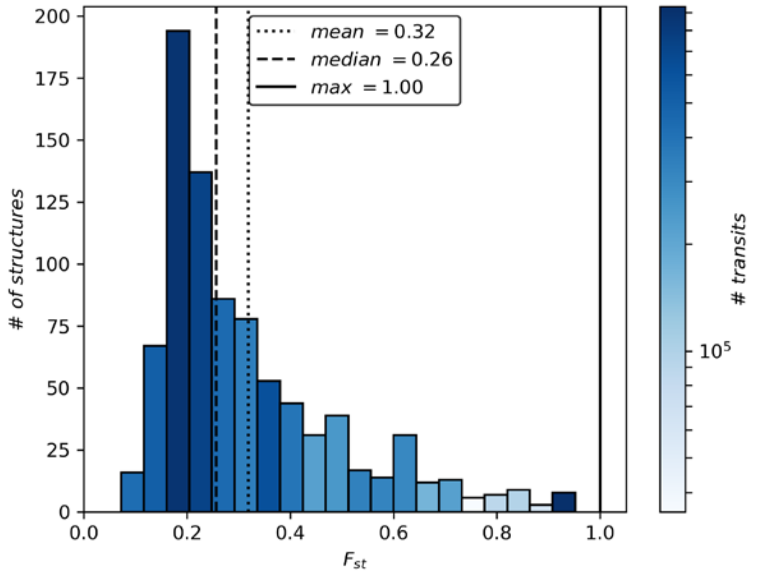
Median Unique in 1 Month – 204.5

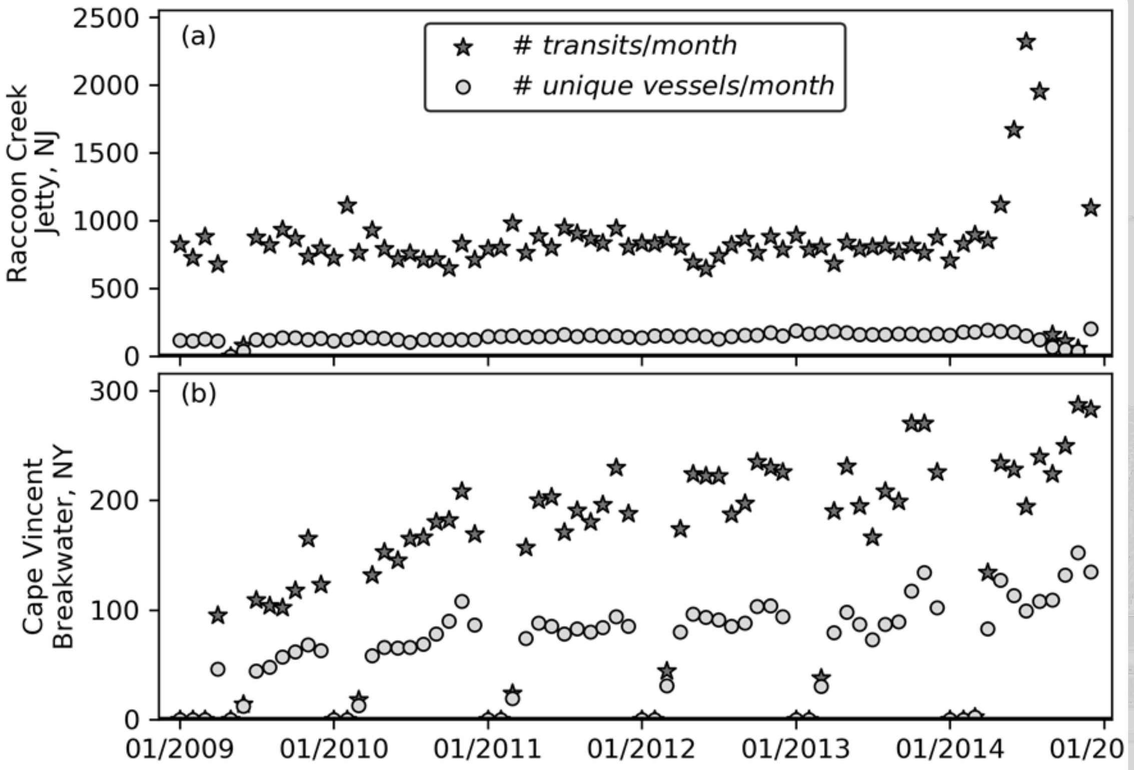




Identifying seasonal structures

- Logging the time of vessel transit results in a time series for each of 1,049 coastal structures where vessel activity was identified within 2 miles of the structure.
- By using the coefficient of determination of the seasonal component of time series decomposition, seasonality can be quantified.

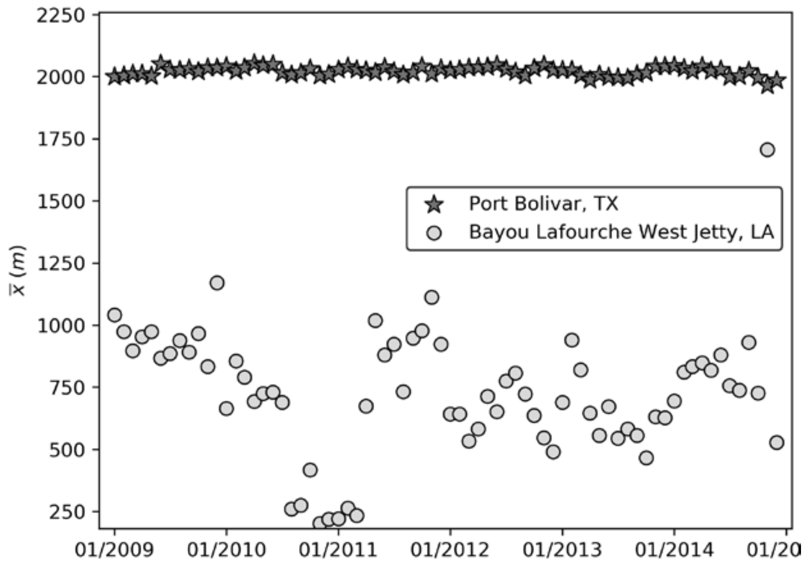


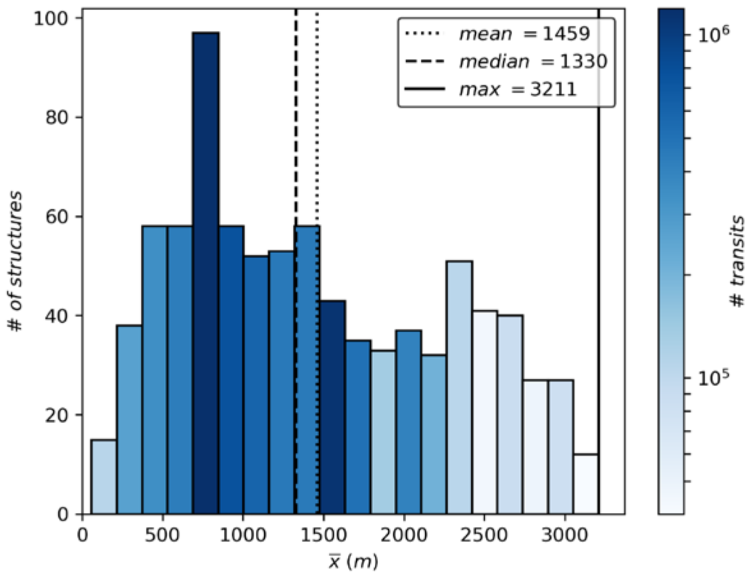


Cape Vincent Breakwater on eastern Lake Ontario is subject to seasonal ice. Western Lake Ontario is mostly ice-free. Structures within a few hundred km on the same body of water at the same latitude may exhibit different lifecycles as a result of ice exposure.

Identifying seasonal structures

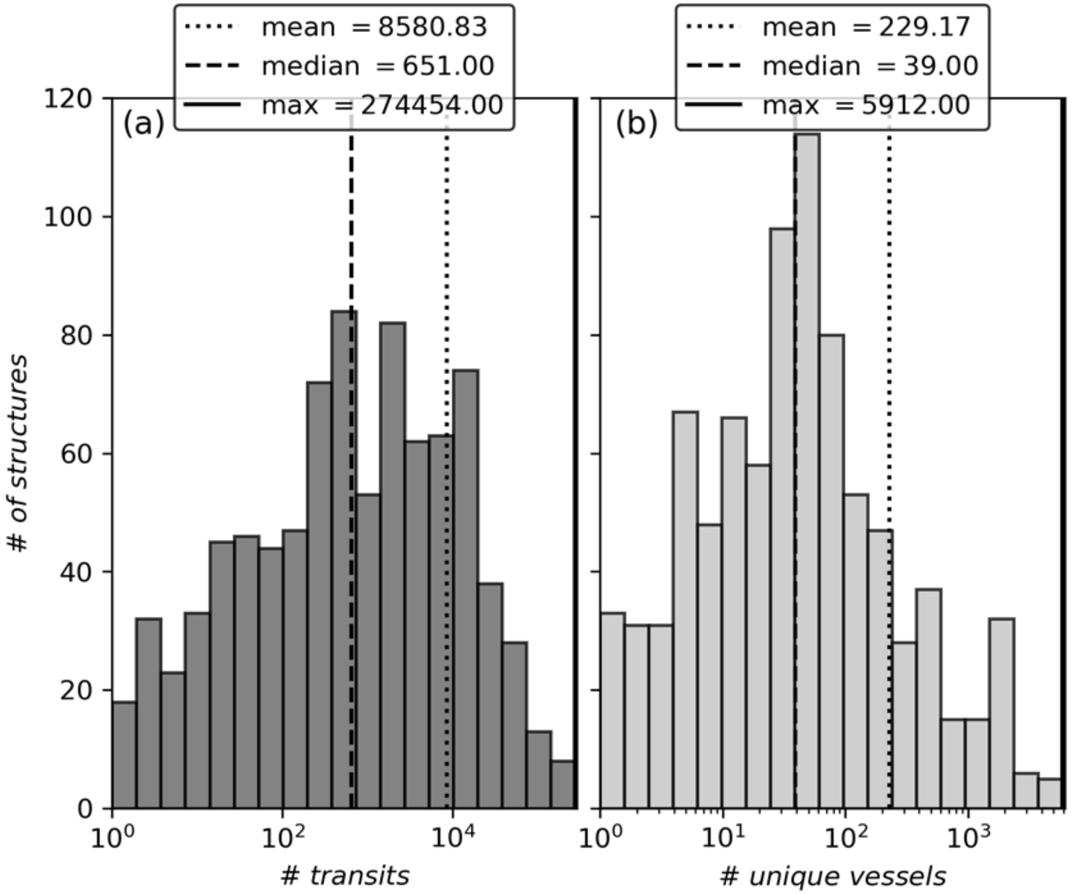
- By measuring the closest point of a vessel's approach to each structure, time series of vessel-structure distance were generated at 1,049 structures.
- The time series for Bayou Lafourche Jetty (near Port Fourchon, LA) shows a period where vessels got much closer to the structure than usual. This period immediately follows the Deepwater Horizon spill. Port Fourchon based vessels service nearly 90% of offshore oil wells in the GoM.





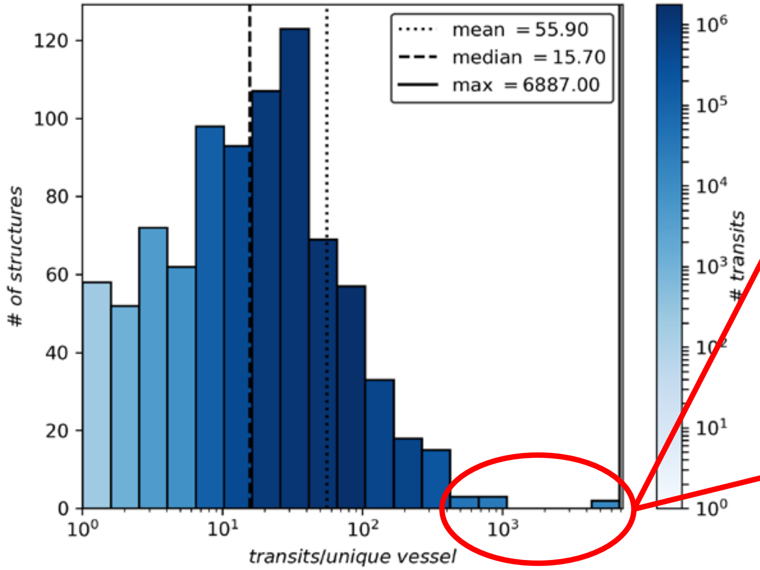
Quantifying size of user base and traffic volume

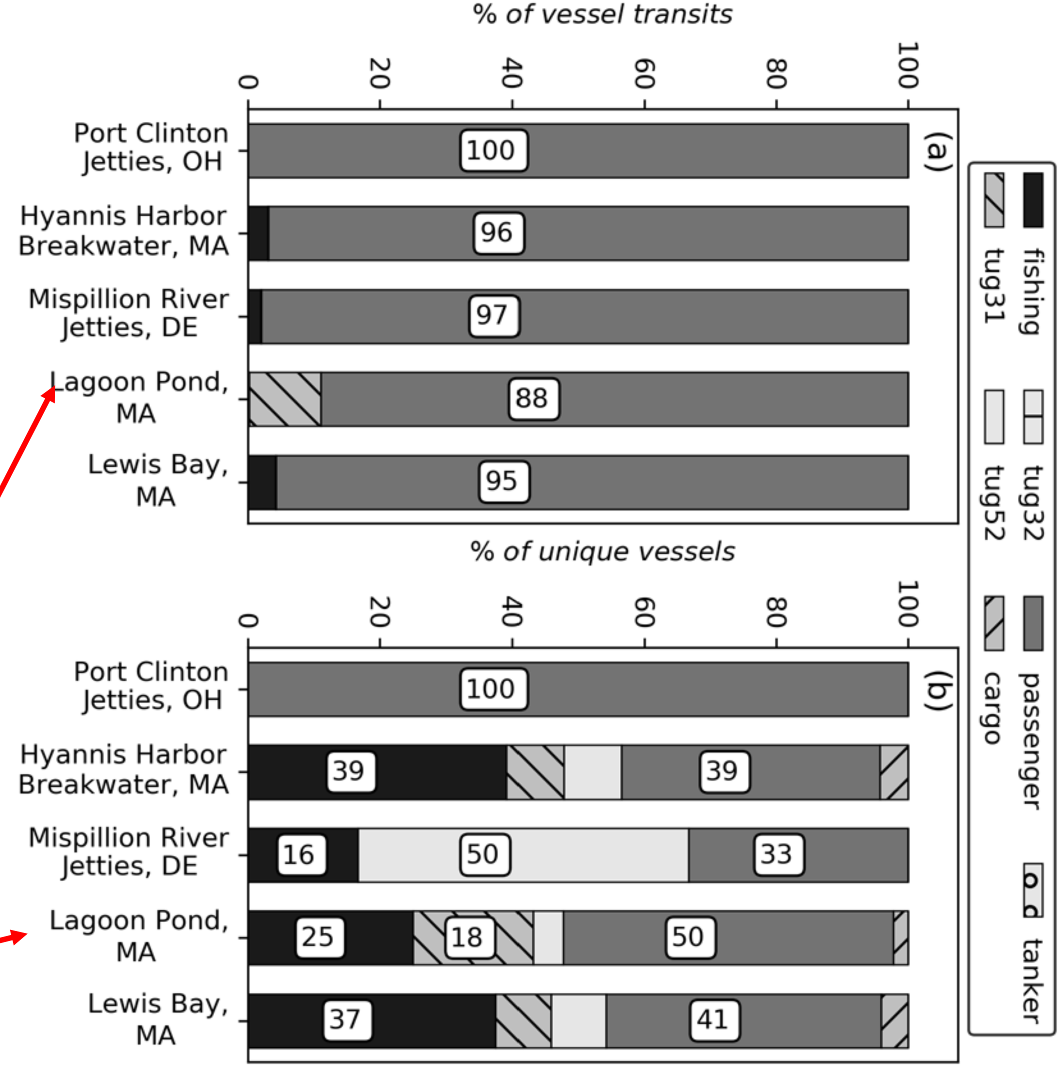
- **AIS documents unique vessel activity so the size of the user base can be quantified as the number of unique users.**
- **The volume of traffic can be quantified as the number of trips by all users.**



Identifying structures with prolific users

- AIS documents unique vessel activity; the ratio trips/unique user characterizes traffic patterns, e.g. where individual vessels make the most transits
- The most prolific users are passenger ferries.
- Structures with the most prolific users tend to be small with evolved population compared to original auth.



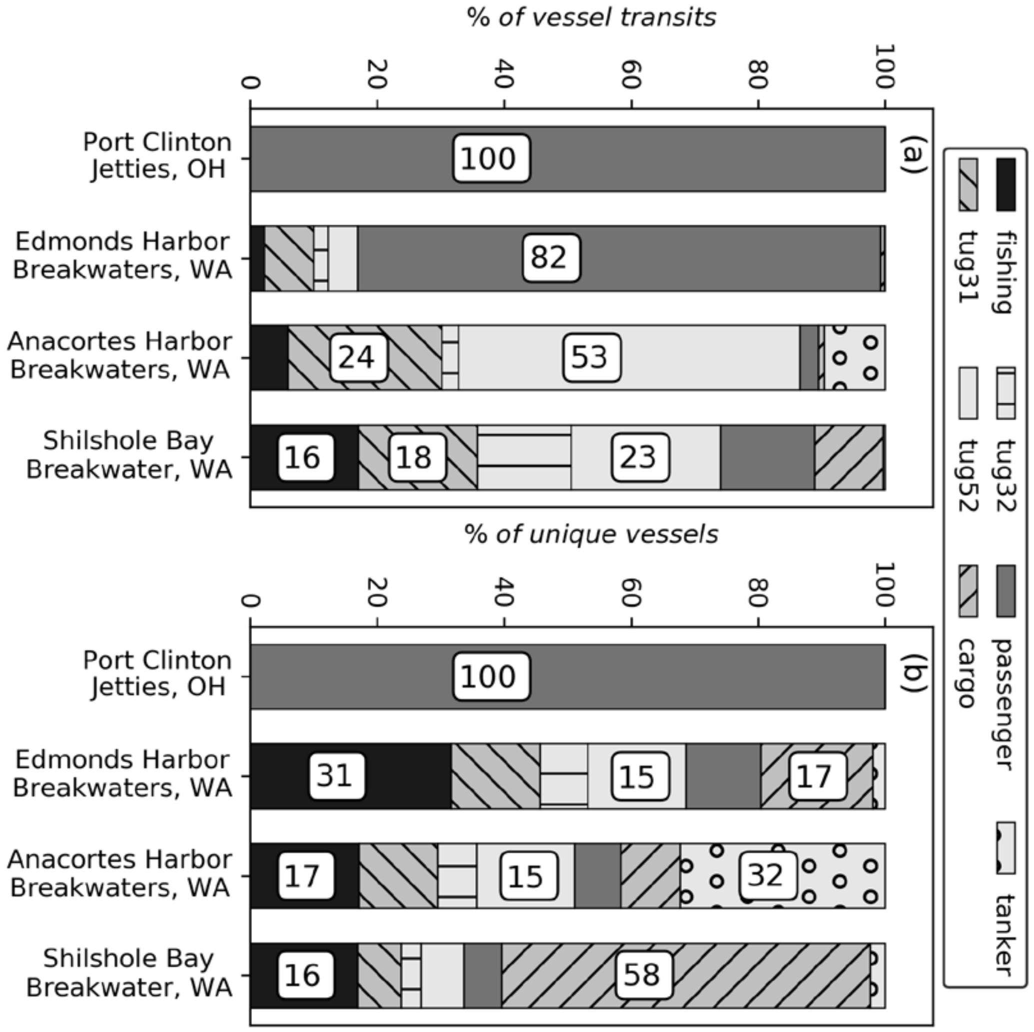


Quantifying user and traffic diversity

- Using information entropy, AIS can be used to quantify the diversity of:
  - Users (entropy of user types)
  - Traffic (entropy of transits by user type)

Increasing Entropy

Increasing Entropy

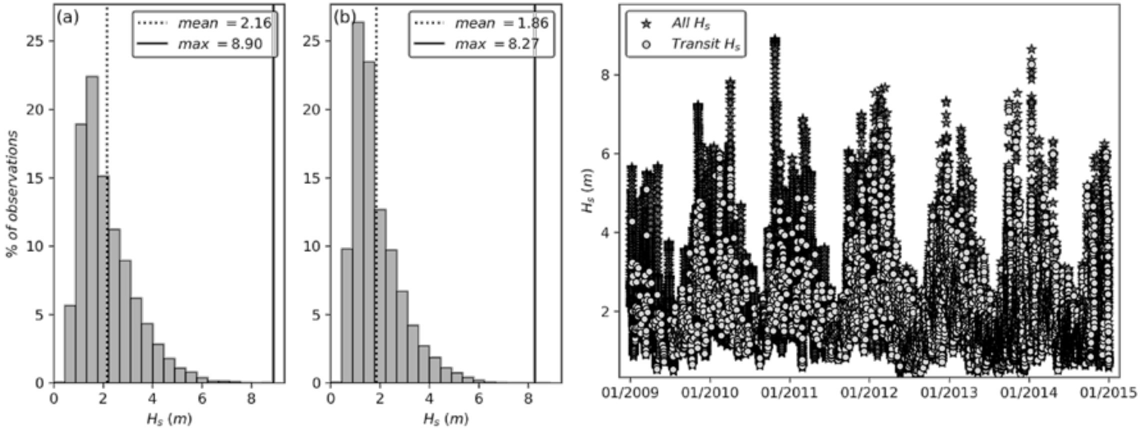


Coupling Vessel Activity with Wave Data

- The timing and distribution of vessel transits can be viewed in context with wave activity.
  - Mean and peak significant wave heights @ time of vessel transit tend to be lower than general mean and peak wave conditions.
  - Structures may demonstrate different traffic signatures when subject to identical traffic conditions.

Grays Harbor S. Jetty

All H_s *Transit H_s*



Grays Harbor N. Jetty

All H_s *Transit H_s*