Spatial-dynamic model of commercial fishing trip decision-making

SPF-2022, W4

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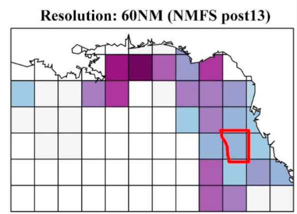
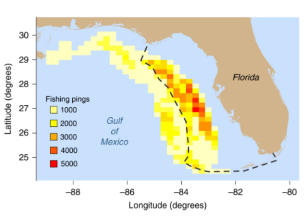
High-resolution movement data enables novel exploration of human behavior.

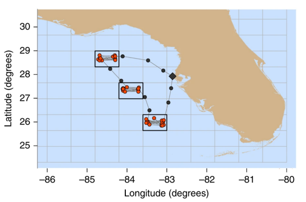
- Satellite GPS vessel tracking data (global pattern of fishing effort, EEZ limit, fishing vessel behaviors)
  - trip-level (logbook) + within-trip (VMS, observer) data from reef fish fishery in Gulf of Mexico, US.



(a) Logbook: trip-level



(b) Fishing heatmap (**hourly VMS**)



(c) Location, path, effort in a simulated track (**VMS+Observer**)

Understand fishing behavior for policy design and evaluation

- Interconnected **within-trip decisions (short run)**:
  - fishing location
  - fishing effort
  - trip length

Understand fishing behavior for policy design and evaluation

- Interconnected **within-trip decisions (short run)**:
  - fishing location
  - fishing effort
  - trip length
- Influencing factors in a commercial fishing trip:
  1. economic opportunities (e.g., stock)
  2. vessel technology constraints (e.g., fuel and hold capacity)
  3. management regime (e.g. area closure)

Research focuses on only one aspect of the interconnected within-trip decisions (fishing location, fishing effort, trip length).

Dominant modeling approach is **location choice**

- static random utility maximization (RUM)
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- studies capturing more dynamics
  - maximize the sum of expected utility during the trip (e.g., Curtis and Hicks (2000); Hicks and Schnier (2008))
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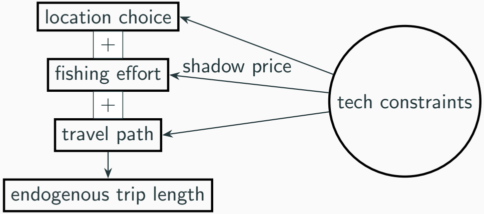
  - exogenous trip length for multi-day trip
    - except Abe and Anderson (2022): endogenous trip length, no location choice

A spatial dynamic model of the interconnected decision



(a) The interconnected trip level decision

(b) Geir - 61,7 m

- Research questions:
  - how can we characterise the dynamically optimal multi-site trip?
  - how is the dynamic model different from the static RUM?
- Conceptual framework and simulation results
- Next step: empirical analysis
- Baseline: perfect knowledge about fish stock (no updating)

Motivation: travelling salesman problem with profits

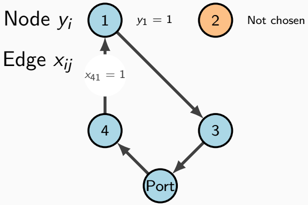


Figure 3: All nodes have a known profit.

Find a **route** that maximizes the collected profits

- from a selection of **nodes**
- subject to travel cost constraints

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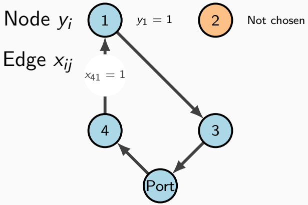

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- open-loop solution: commit to the plan made at port

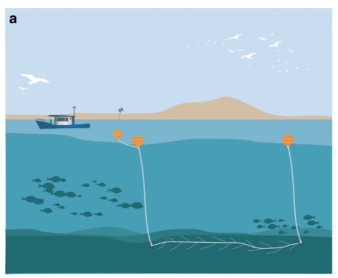
The adapted fishery problem adding Effort_i

$$
\begin{aligned}
\max_{x_{ij},y_i,\text{Effort}_i} \quad & \sum_{i\in N}[p \times \text{harvest}_i(\textbf{Effort}_i, \textbf{y}_i) - c_{fuel} \times \text{fishing fuel use}_i(\textbf{Effort}_i)] - \sum_{(i,j)\in E} c_{fuel} \times \text{travel fuel use}_{ij}(\textbf{x}_{ij}) \\
\text{s.t.} \quad & \sum_{i\in N} \text{fishing fuel use}_i(\textbf{Effort}_i) + \sum_{(i,j)\in E} \text{travel fuel use}_{ij}(\textbf{x}_{ij}) \leq \; \text{F}_{max} \quad \text{Fuel constraint} \\
& \textstyle\sum_{i\in N} \text{harvest}_i(\textbf{Effort}_i, \textbf{y}_i) \leq \; \text{C}_{max} \quad \text{Hold constraint} \\
& \text{Subtour elimination} \;\; \text{example} \\
& \text{Connectivity constraints} \\
\textbf{choices:} \quad & \underbrace{\textbf{Effort}_i}_{\text{fishing hours}} \text{ continuous, } \underbrace{\textbf{x}_{ij}}_{\text{path}}, \underbrace{\textbf{y}_i}_{\text{node}} \in \; \{0,1\}
\end{aligned} \tag{1}
$$

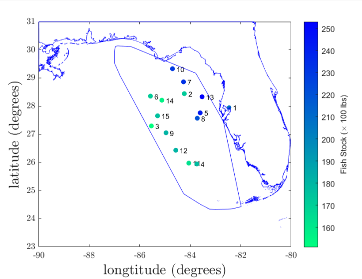
- A discrete-continuous problem
- Time is endogenous to spatial choice and fishing effort
- Dynamic fisher: a sequence of choices (open loop solution)
- Myopic fisher (static RUM): site-by-site choice (rolling max)

Set up - Gulf of Mexico bottom longline fishery

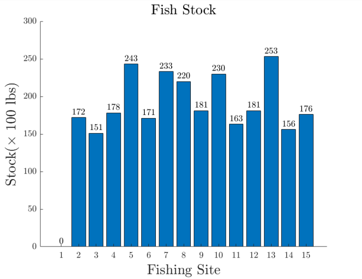
- Fish stock assumptions
  - Spatial pattern: higher fish stock at nearshore sites
  - Fishers know the fish stock distribution



(a) Bottom longlines



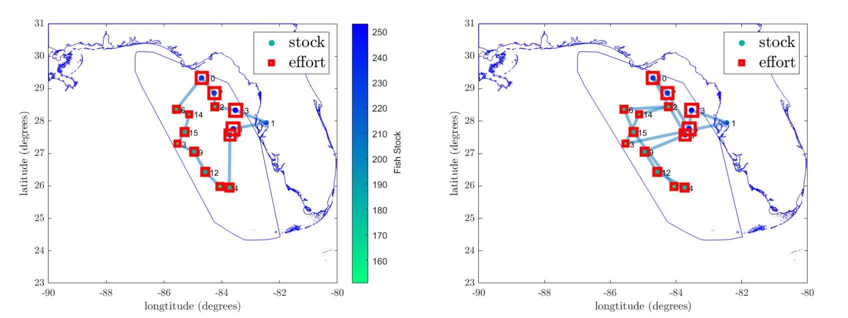
(b) 14 Fishing Sites



(c) Fish Stock

Results with non-binding fuel and hold constraints

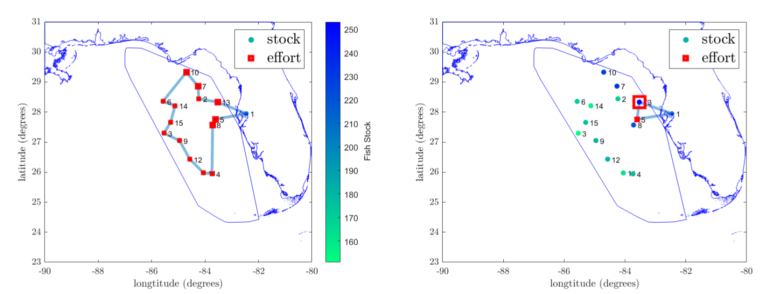
- Visit all sites, same fishing effort ($\frac{\partial \pi}{\partial \text{effort}_i} = 0$)
- Dynamic: route with minimal travel cost
- Myopic: no route planning (following the order of stock)
- $\Rightarrow \pi_{myopic} \approx 0.9\pi_{dynamic}$



(a) Dynamic **(b)** Myopic

Results with binding fuel constraint

- ($H_i = q\text{Effort}_i^{\gamma}\text{Stock}_i$, $\gamma < 1$)diminishing marginal harvest to effort $\Rightarrow$spread effort
- Dynamic: effort allocated s.t. $\frac{\partial \pi}{\partial \text{effort}_i} = \lambda_{fuel} \times$ fuel use per effort
- Myopic: concentrated effort, fewer sites
- $\Rightarrow \pi_{myopic} \approx 0.44\pi_{dynamic}$
- Trip length: dynamic-15 days (9.75d fishing), myopic-13 days (11.7d fishing)



(a) Dynamic **(b)** Myopic

Summary: dynamic vs myopic

- The dynamic fisher (spatial-dynamic model) differs from the myopic fisher (static RUM)
  - forward-looking:
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    - technology constraints affecting the whole trip: shadow price

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- The myopic fisher suffers profit loss from
  1. constrained route planning
  2. ignoring the technology constraints
  - unconstrained: $\pi_{myopic} \approx 0.9\pi_{dynamic}$
    - loss from constrained route planning
  - fuel binding: $\pi_{myopic} \approx 0.44\pi_{dynamic}$

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  - fuel binding: $\pi_{myopic} \approx 0.44\pi_{dynamic}$
- To decompose the loss with binding technology constraints
  - consider an m-site choice partially myopic fisher

m-site choice (partially) myopic fisher

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  - at every chosen location, re-optimize by choosing another m sites + port
  - repeats until back to the port

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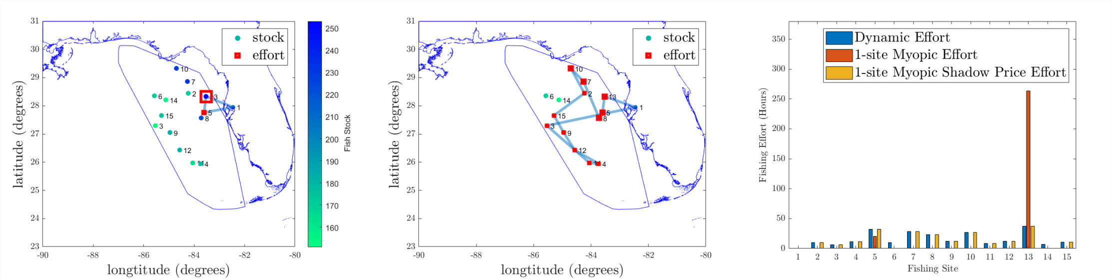
- Suppose a binding fuel constraint
  - for the dynamic fisher

$$\frac{\partial \mathcal{L}}{\partial \text{Effort}_i} = p \frac{\partial \text{harvest}_i}{\partial \text{Effort}_i} - (c_{fuel} + \lambda_{fuel}) \frac{\partial \text{fishing fuel use}_i}{\partial \text{Effort}_i} = 0 \tag{2}$$

  - suppose λ_{fuel} is known to the (partially) myopic fisher
    - loss from constrained route planning

1-site choice myopic fisher

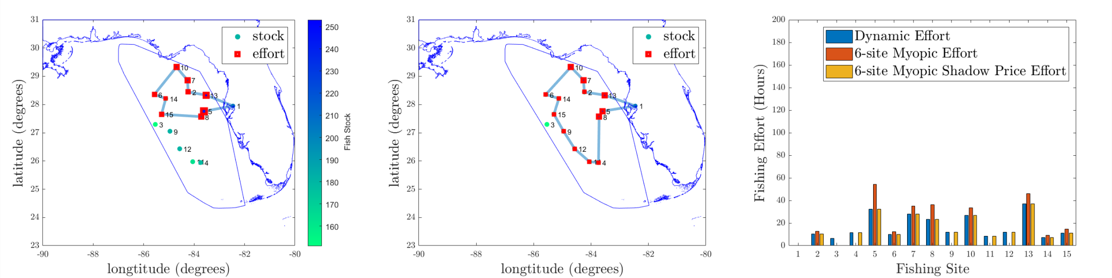
- $\pi_{myopic} = 0.44\pi_{dynamic}$, 2 sites
- $\pi_{myopic,\lambda_{fuel}} = 0.86\pi_{dynamic}$, 12 sites
  - Profit ↑ 42% by considering the fuel constraint
    - no concentrated effort at Site 13
    - saved fuel ⇒ visiting and fishing at more sites
  - 14% loss from constrained route planning
    - 0.2% fuel left



(a) Myopic **(b)** λ_{fuel} embedded **(c)** Effort

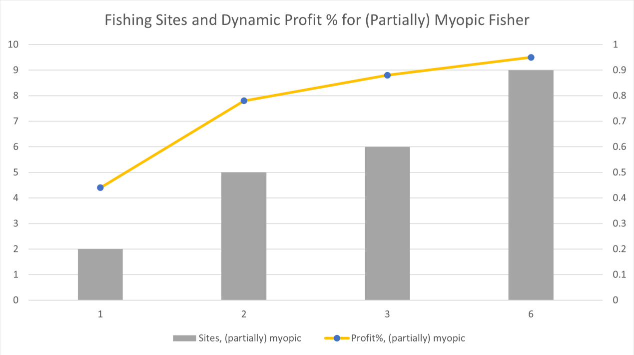
6-site choice partially myopic fisher

- $\pi_{6site} = 0.95\pi_{dynamic}$, 9 sites
- $\pi_{6site,\lambda_{fuel}} = 0.97\pi_{dynamic}$, 13 sites
    - Profit $\uparrow$ 2% by considering the fuel constraint
        - saved fuel $\Rightarrow$ visit and fishing at more sites
    - 3% loss from constrained route planning
        - 2.8% fuel left



(a) 6-site partially myopic **(b)** λ_{fuel} embedded **(c)** Effort

Summary: $m \uparrow$, partially myopic fisher approaches dynamic fisher



- Better forward-looking increases profit
  - route planning
  - consideration of technology constraint
    - spatially spreading effort

Conclusions

- A spatial-dynamic model of interconnected trip-level decisions on
    - fishing location
    - fishing effort
    - travel route
    - (trip length)
- The spatial-dynamic model differs from the static RUM
    - forward-looking:
        - route planning
        - technology constraints affecting the whole trip
- Fishers are heterogeneous in
    - technology constraints (small vs large)
    - degree of forward-looking (dynamic, myopic, m-sites partially myopic)
- Use the model to predict heterogeneous short-run impacts of policies (area closure/MPAs)
    - smaller vessels have more constrained fuel and hold capacity
    - for long-run impacts, combine fish population dynamics

Small Pelagic Fish (SPF)

- Current assumptions: stock is known at the port and doesn't change in the trip.
  - GoM Reef-fish fishery trip length: 2- 20 days
- SPF: large fluctuations in abundance and distribution
  - stock uncertainty
  - information updating (learning and sharing)
- Model modification: information update and re-optimization
  - Partial knowledge: $\text{Stock}_i \overset{i.i.d.}{\sim} \mathcal{N}(\mu_i, \sigma_i^2)$
    - no spatial correlation
    - w/o information sharing: fishing at current site only update belief of own sites - update at the trip level
    - w information sharing: update at an exogenous level
  - Partial knowledge+ spatial correlation
    - passive learning: fishing at current site updates beliefs at correlated sites
    - active learning: search vs fishing
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