Cooperative and Non-Cooperative Strategies for Management of Bering Sea Pollock

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Take-Home

- Straddling stocks subject to discordant management regimes produce suboptimal levels of socioecological benefits.
- Coordinated management of straddling stocks is particularly difficult when:
  - the stock is migratory, the spatial distribution of the stock varies, or biomass and recruitment are highly variable or uncertain;
  - management/social objectives, risk aversion, time preferences, or expectations about future access to the stock differ; or
  - product prices, input costs, or access to capital are variable, uncertain, or differ.

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The dynamics of pollock can be represented as:

$$(1) \quad \mathbf{X}_{\alpha,t} = f\begin{pmatrix} \mathbf{X}_{\alpha,t-1}\cdots\mathbf{X}_{\omega,t-l}, \mathbf{Y}_{\alpha,t-1}\cdots\mathbf{Y}_{\omega,t-m}, \\ \mathbf{Z}_{\alpha,t-1}\cdots\mathbf{Z}_{\omega,t-k}, \mathbf{K}_{\alpha,t-1}\cdots\mathbf{K}_{\omega,t-j} \end{pmatrix} + \boldsymbol{\varepsilon}_t$$

where for areas α … ω and lags 1 … l,

- **X** reflects pollock age-class biomasses,
- **Y** reflects the age-class biomasses of other species,
- **Z** is a matrix of the of environmental factors,
- **K** is a matrix of fishing mortalities, enhancement activities, and other controls

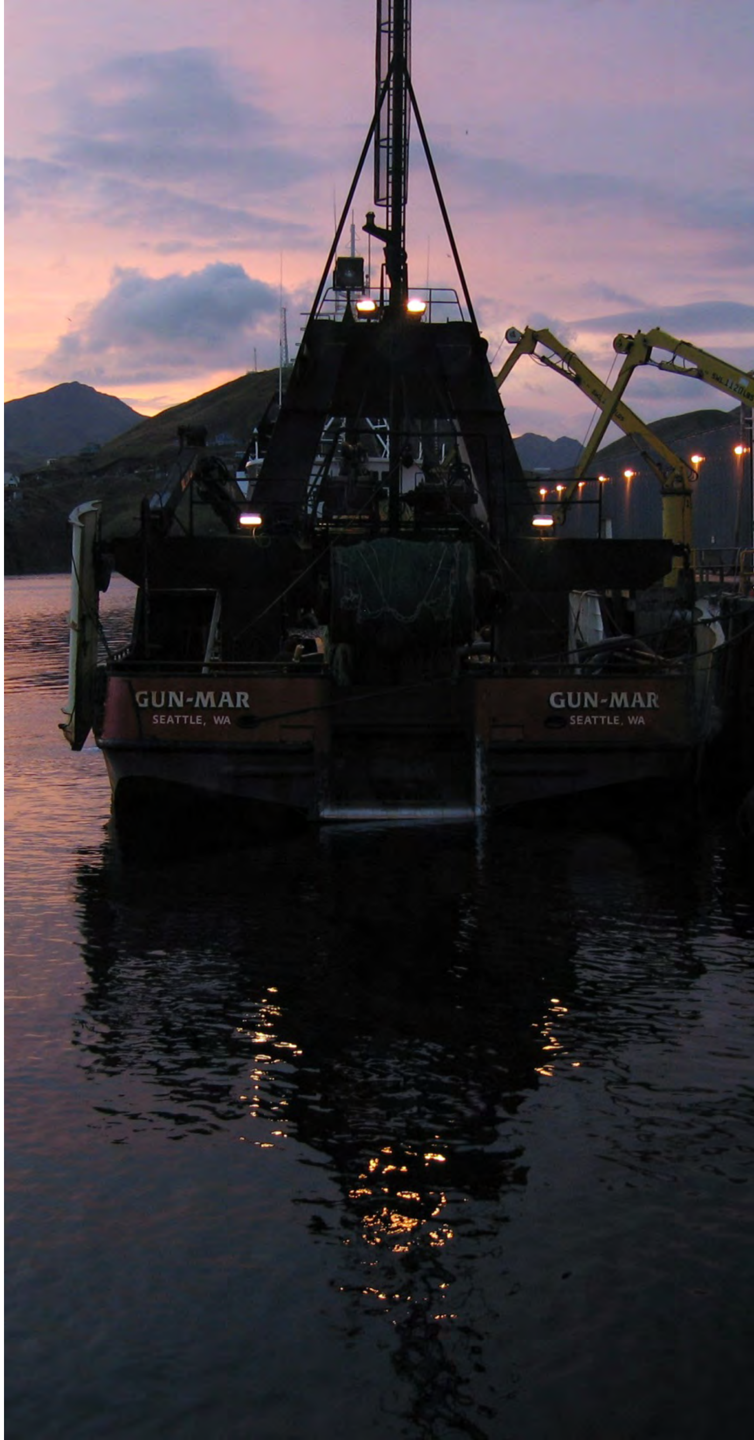
It is usually assumed that *f*(•) is observable, that **X**, **Y** and **Z** are observable and stationary, and that **K** is controllable.

Unexplained variability, **ε**, may be characterized by contemporaneous and serial correlations; it may also include errors associated with the observation (measurement) of **X**, **Y**, and **Z**, errors associated with misspecification of ***f*(•)**, and errors in the observation (measurement) and implementation (controllability) of **K**.

Equation (1) describes changes in contemporaneous values of **X** conditional on lagged values of **X, Y**, **Z**, and **K**.

Any predictions about future values of **X** will be contingent on:

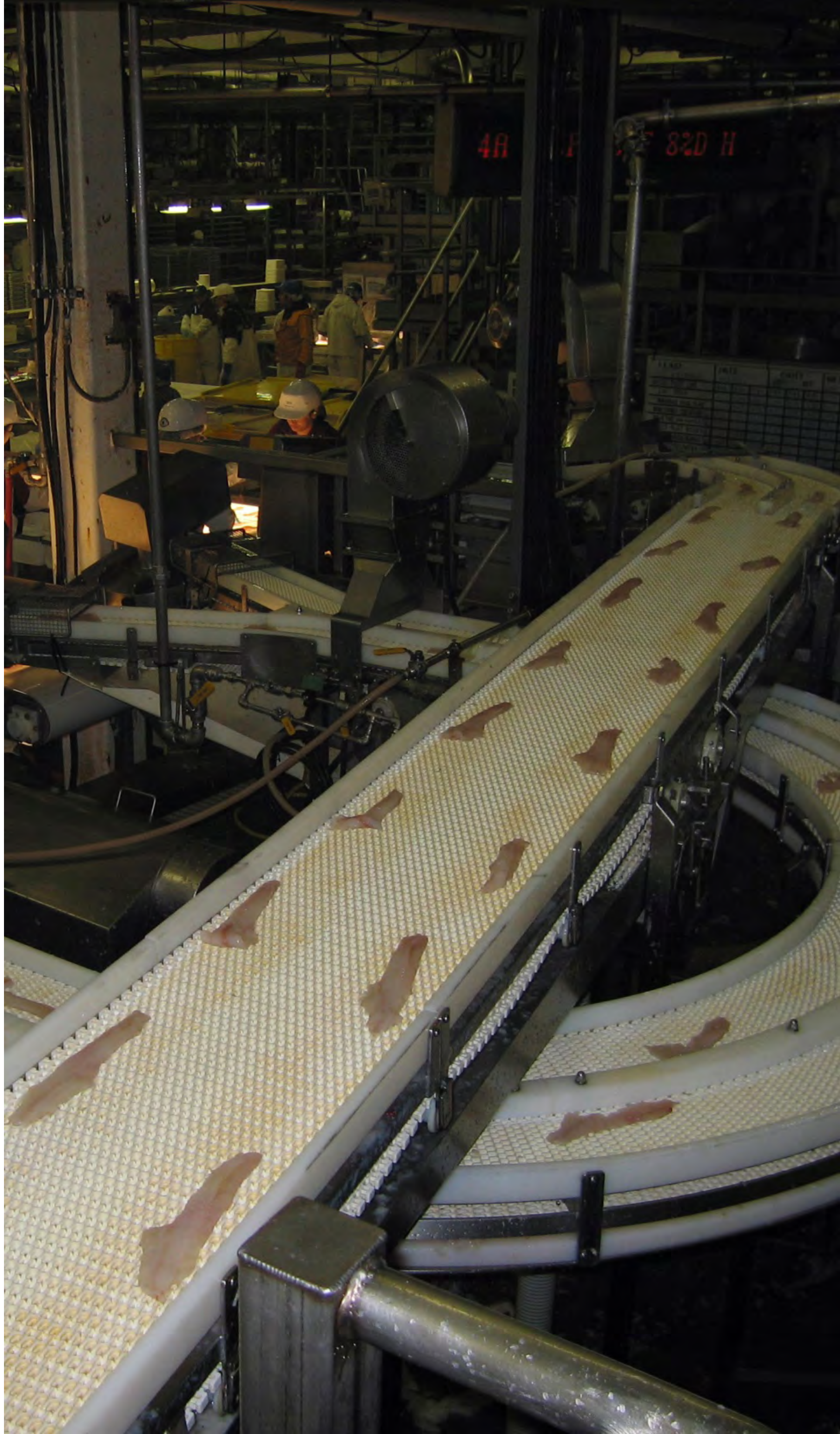
- correct specification of *f*(•),
- the quality of predictions about **Y**, **Z**, and **K**,
- the validity of the assumption that the variables are observable and controllable, and
- the validity of the stationarity assumption or the validity of characterizations of the nature of nonstationarities



While equation (1) describes **feasible** states of nature, it does not identify **preferred** states of nature.

That is, equation (1) does not represent management objectives.

Management objectives are often framed in terms of maximization of expected utility or minimization of expected regrets.



A utility maximization objective can be represented by:

(2) $$max\ \mathbf{EU} = \sum_{t=-\infty}^{\infty} \sum_{a=\alpha}^{\omega} g\begin{pmatrix} \mathbf{X}_{a,t}, \mathbf{Y}_{a,t}, \mathbf{Z}_{a,t}, \\ \mathbf{K}_{a,t}, r_a, \eta_a \end{pmatrix}$$

where **EU** is the total risk-adjusted expected net utility that society derives from given combinations of **X, Y**, **Z**, and **K**, ***r*** is the social rate of time preference, and $\boldsymbol{\eta}$ represents risk aversion.

A minimum expected regret objective can be represented by:

$$(2') \qquad \min \mathbf{ER} = \sum_{t=-\infty}^{\infty} \sum_{a=\alpha}^{\omega} g * \begin{pmatrix} \mathbf{X}_{a,t} - \mathbf{X}^*, \mathbf{Y}_{a,t} - \mathbf{Y}^*, \\ \mathbf{Z}_{a,t} - \mathbf{Z}^*, \mathbf{K}_{a,t} - \mathbf{K}^*, \\ r_a, \eta_a \end{pmatrix}$$

where **X***, **Y***, **Z***, and **K*** are preferred states and ***g*(•)** reflects the disutility of deviations from the preferred states.

Equation (2) describes preferences about alternative states of nature and controls but does not ensure that preferred solutions are feasible. Implicit in the specification of equation (2) are assumptions that:

- utility associated with stocks and flows of use and nonuse benefits can be reified
- individuals are rational and act in their own perceived interest
- ***g*(•)** is a convex hull
- mechanisms exist for reconciling gains and losses across individuals
- controls are legally permissible, efficacious, and enforceable

Equations (1) and (2), together with admissibility restrictions, represent the pollock socio-ecological system as a stochastic constrained optimization.

$$(3)\quad max(\mathsf{E}\mathbf{U}) = \sum_{t=-\infty}^{\infty} \sum_{a=\alpha}^{\omega} g\left(\mathbf{X}_{a,t}, \mathbf{Y}_{a,t}, \mathbf{Z}_{a,t}, \mathbf{K}_{a,t}, r_a, \eta_a\right)$$

$$\mathbf{X}_{\alpha,t} = f\begin{pmatrix} \mathbf{X}_{a,t-1} \ldots \mathbf{X}_{\omega,t-l}, \mathbf{Y}_{\alpha,t-1} \cdots \mathbf{Y}_{\omega,t-m}, \\ \mathbf{Z}_{\alpha,t-1} \ldots \mathbf{Z}_{\omega,t-k}, \mathbf{K}_{\alpha,t-1} \ldots \mathbf{K}_{\omega,t-j} \end{pmatrix} + \boldsymbol{\varepsilon}_t$$

$$\mathbf{X}_{a,t} \geq 0 \quad \mathbf{X}_{a,t} \geq \mathbf{K}_{a,t} \geq 0 \quad \mathbf{Y}_{a,t} \geq 0$$

Games & Fish

Management of a straddling stock can be characterized as a two-party game.

Solutions and the value of solutions to two-party games depend on the extent to which each player strategizes—takes into account the likely actions of the other player.

A Bioeconomic Game with Two Regions

$$(3^{\dagger}) \quad max\left(\mathrm{EU}\right) = \sum_{t=0}^{\infty} g\left(\mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{h}_{1,t}, \mathbf{h}_{2,t}, r_1, r_2, \eta_1, \eta_2\right)$$

$$\begin{pmatrix} \mathbf{h}_{1,t} \\ \mathbf{h}_{2,t} \end{pmatrix} = f'\begin{pmatrix} \mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{X}_{1,t-1}, \mathbf{X}_{2,t-1}, \\ \mathbf{Y}_{1,t-1}, \mathbf{Y}_{2,t-1}, \mathbf{Z}_{1,t-1}, \mathbf{Z}_{2,t-1} \end{pmatrix} + \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{pmatrix}$$

Overall utility is a function of the stock and catches in both areas, the social rate of discount and the risk aversion coefficient for each area and area-specific harvest rules that depend on current and lagged abundance of the target species, lagged abundances of trophically related species, environmental processes and contemporaneous and serially correlated stochastic processes.

A Bioeconomic Game with Two Regions

If $\boldsymbol{f}(\bullet)$ and $\boldsymbol{g}(\bullet)$ are additively separable between regions, that is if

1. the target species is not transboundary,
2. important trophic relationships are not transboundary,
3. environmental feedbacks are not transboundary , and
4. economic and other social factors are independent between regions,

then $(3^{\dagger})$ can be written as two additively separate functions that can be independently optimized.

A Bioeconomic Game with Two Independent SES

$$max\left(\mathbf{E}\mathrm{U}\right)=\sum_{t=0}^{\infty} g_1\left(\mathbf{X}_{1,t},\mathbf{h}_{1,t},r_1,\eta_1\right)+\sum_{t=0}^{\infty} g_2\left(\mathbf{X}_{2,t},\mathbf{h}_{2,t},r_2,\eta_2\right)$$

$$\mathbf{h}_{1,t} = f_1'\left(\mathbf{X}_{1,t},\mathbf{X}_{1,t-1},\mathbf{Y}_{1,t-1},\mathbf{Z}_{1,t-1}\right)+\boldsymbol{\varepsilon}_{1,t}$$

$$\mathbf{h}_{2,t} = f_2'\left(\mathbf{X}_{2,t},\mathbf{X}_{2,t-1},\mathbf{Y}_{2,t-1},\mathbf{Z}_{2,t-1}\right)+\boldsymbol{\varepsilon}_{2,t}$$

or

$$max\left(\mathbf{E}\mathrm{U}_1\right)=\sum_{t=0}^{\infty} g_1\begin{pmatrix}\mathbf{X}_{1,t},\mathbf{h}_{1,t}, \\ r_1,\eta_1\end{pmatrix} \qquad max\left(\mathbf{E}\mathrm{U}_2\right)=\sum_{t=0}^{\infty} g_2\begin{pmatrix}\mathbf{X}_{2,t},\mathbf{h}_{2,t}, \\ r_2,\eta_2\end{pmatrix}$$

$$\mathbf{h}_{1,t} = f_1'\begin{pmatrix}\mathbf{X}_{1,t},\mathbf{X}_{1,t-1}, \\ \mathbf{Y}_{1,t-1},\mathbf{Z}_{1,t-1}\end{pmatrix} \qquad \mathbf{h}_{2,t} = f_2'\begin{pmatrix}\mathbf{X}_{2,t},\mathbf{X}_{2,t-1}, \\ \mathbf{Y}_{2,t-1},\mathbf{Z}_{2,t-1}\end{pmatrix}$$

$$+\boldsymbol{\varepsilon}_{1,t} \qquad +\boldsymbol{\varepsilon}_{2,t}$$

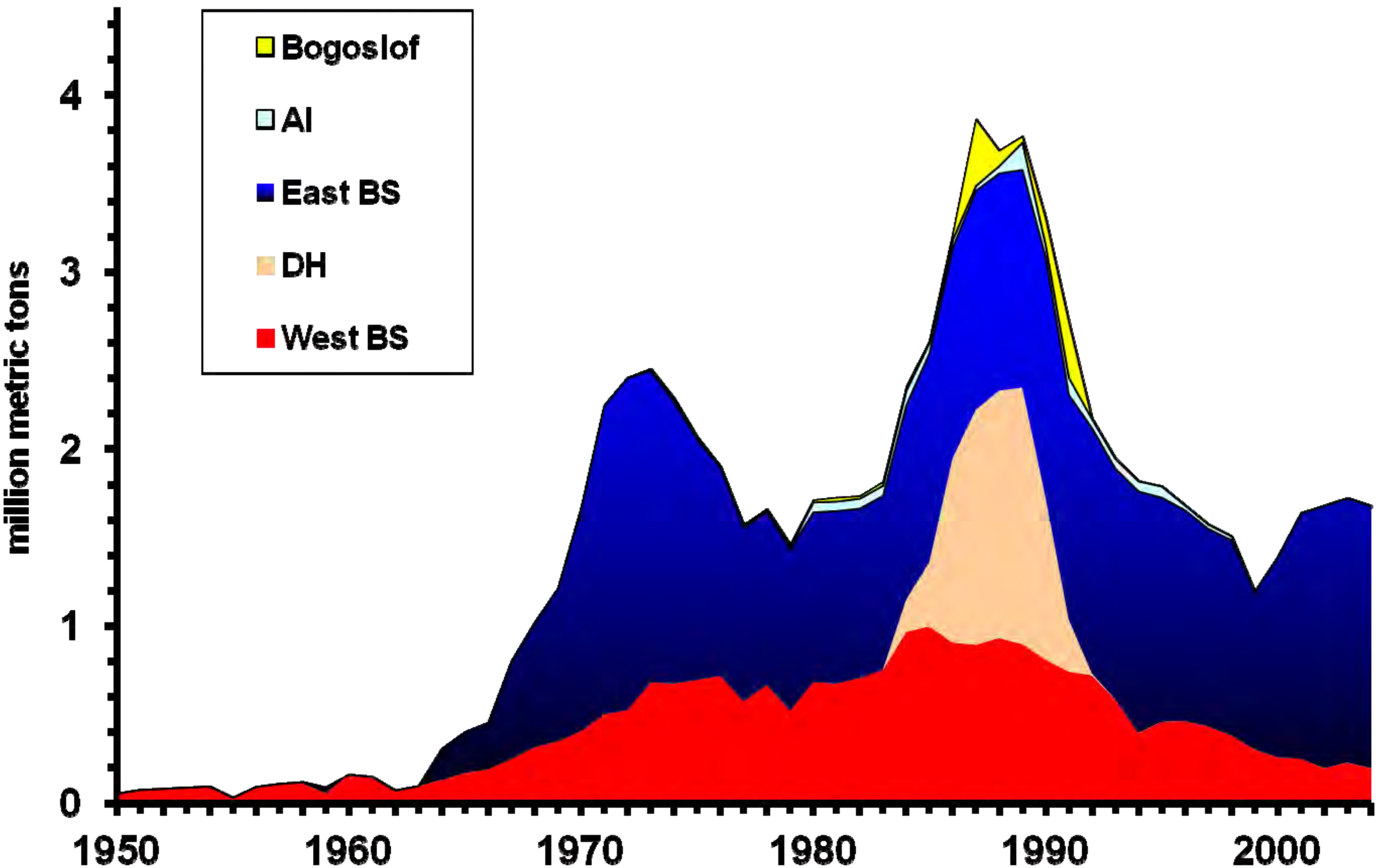
A Bioeconomic Game with Two Regions

For the eastern Bering Sea pollock stock, ***f*(•)** and ***g*(•)** are not additively separable between regions:

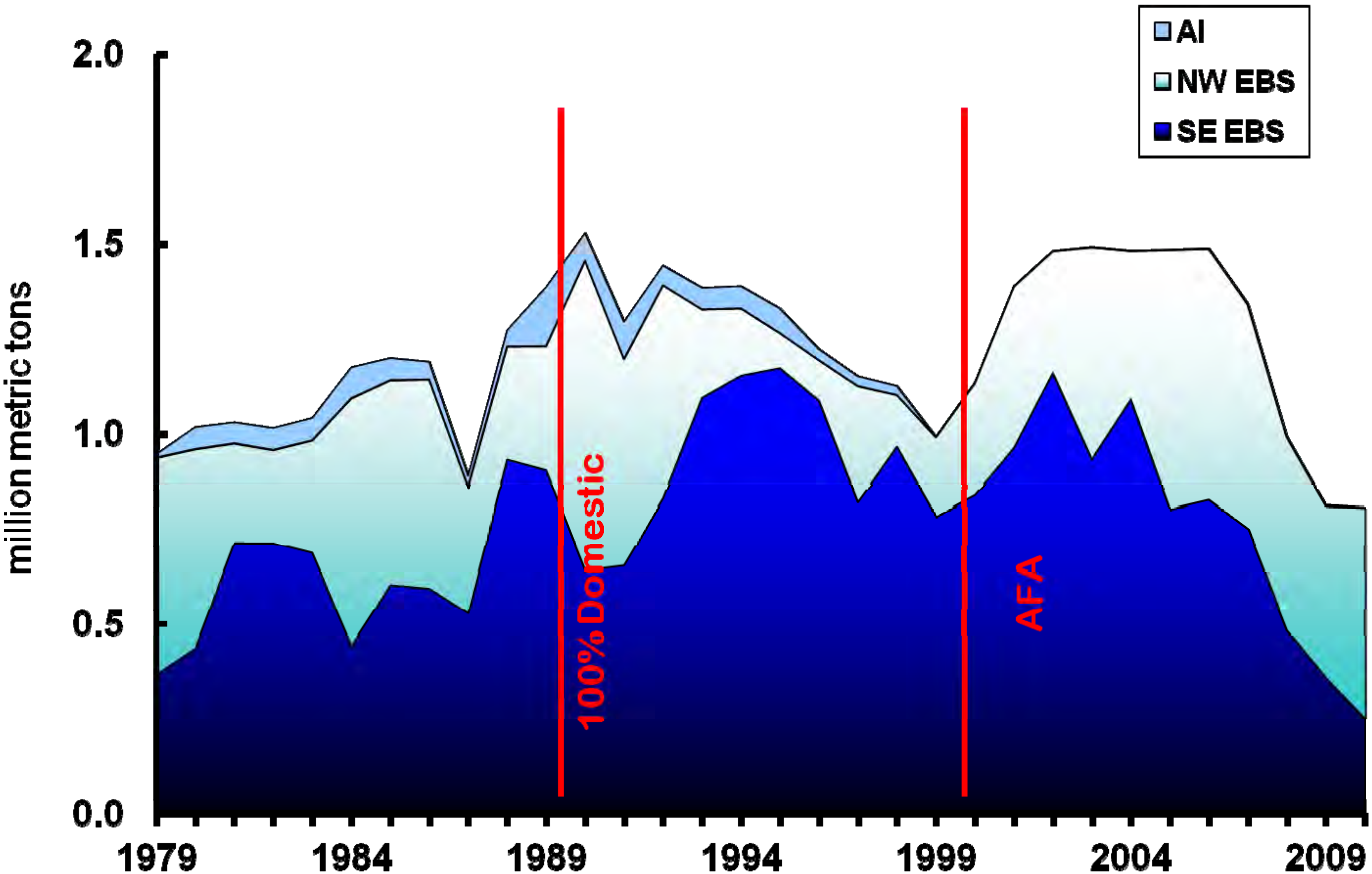
1. the target species is transboundary,
2. important trophic relationships are transboundary, and
3. input and output markets are linked.

Consequently, regionally independent utility maximization will result is a solution the is suboptimal overall and may be infeasible over time.

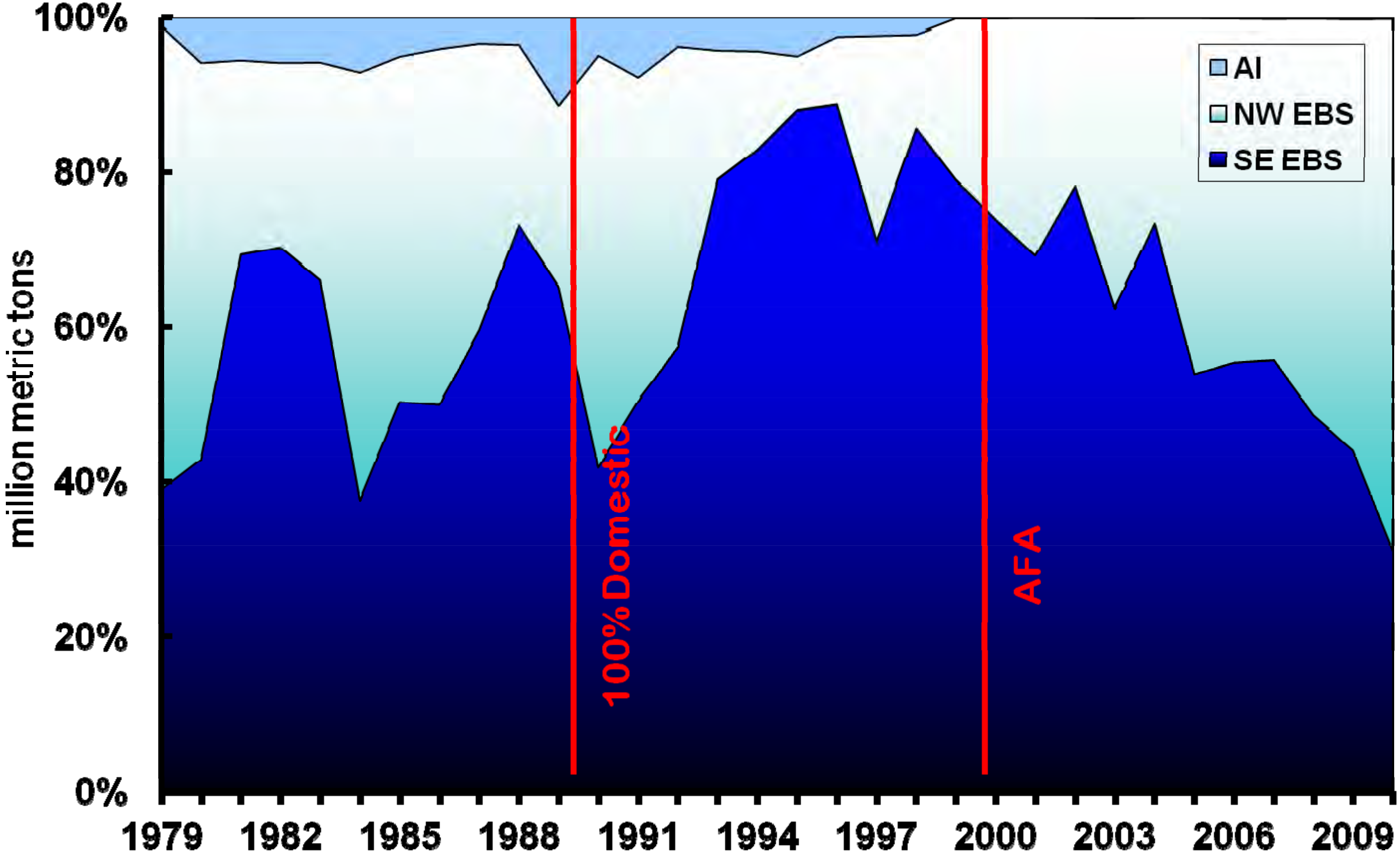
Pollock Catches—Bering Sea



Pollock Catches—Eastern Bering Sea

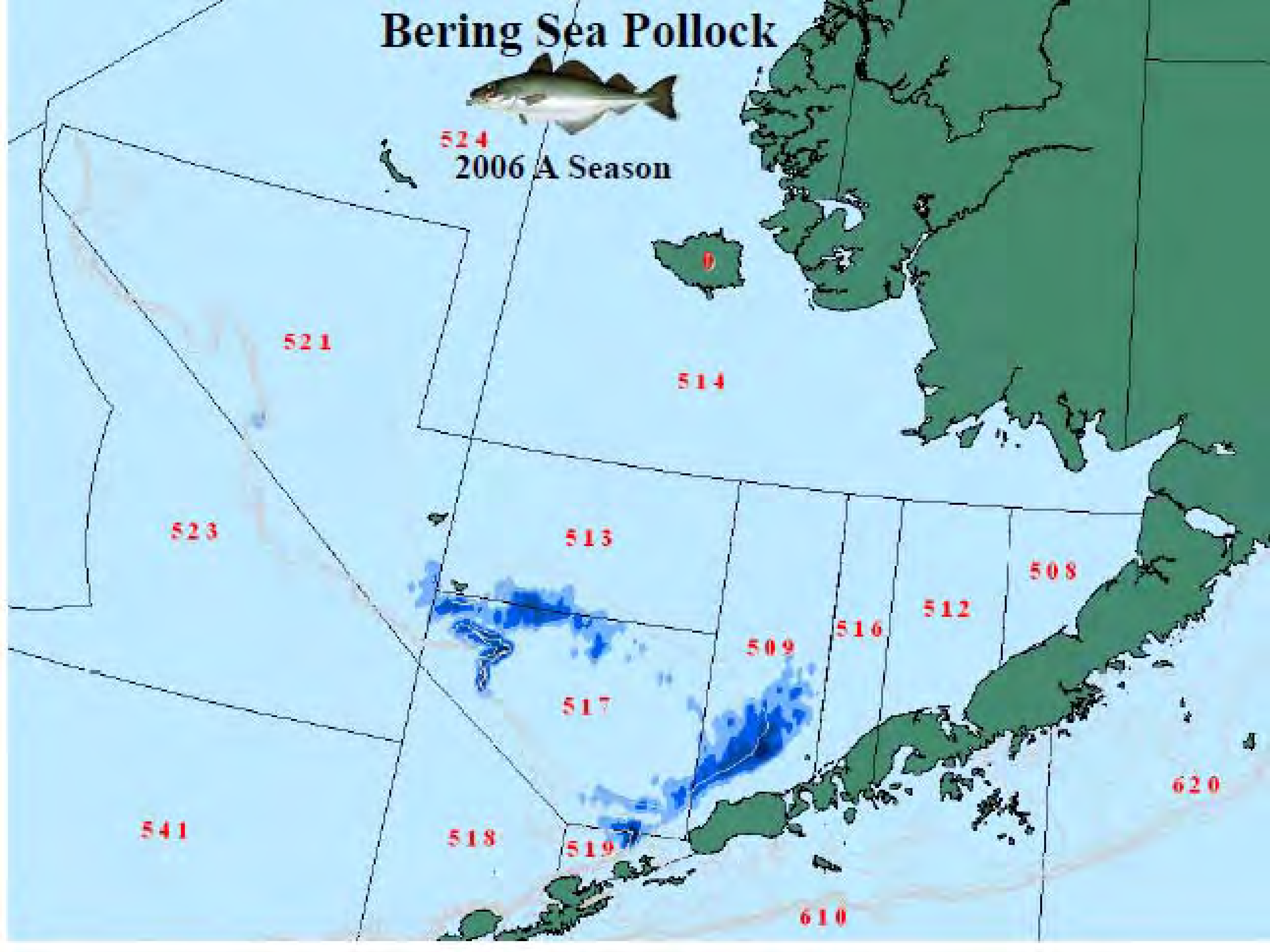


Pollock Catches—Eastern Bering Sea



Eastern Bering Sea Pollock—A Transboundary Stock

The abundance and spatial distribution of EBS pollock varies through time such that variable portions of the stocks are exposed to harvesting by vessels in the Russian EEZ.



Bering Sea Pollock
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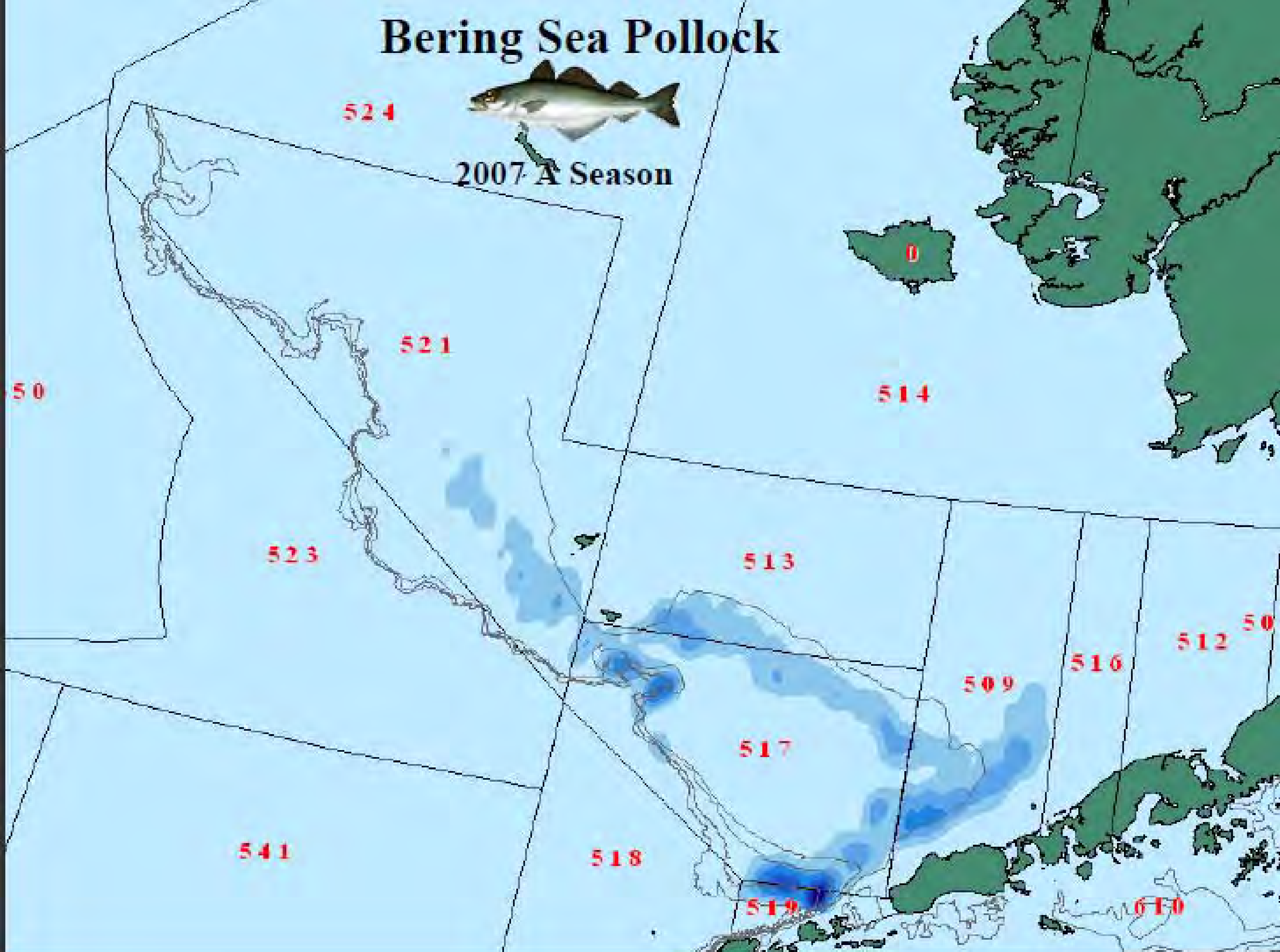
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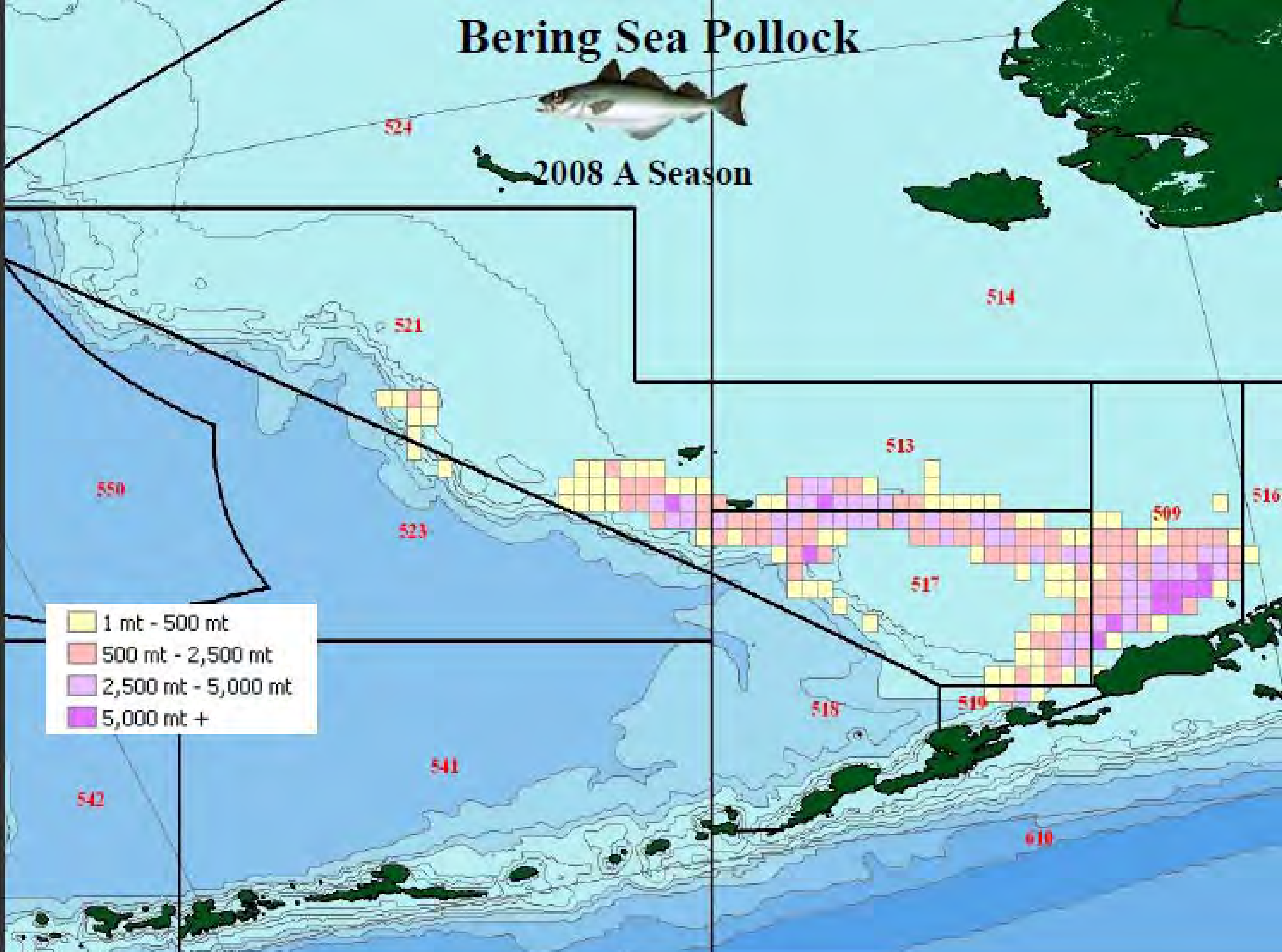
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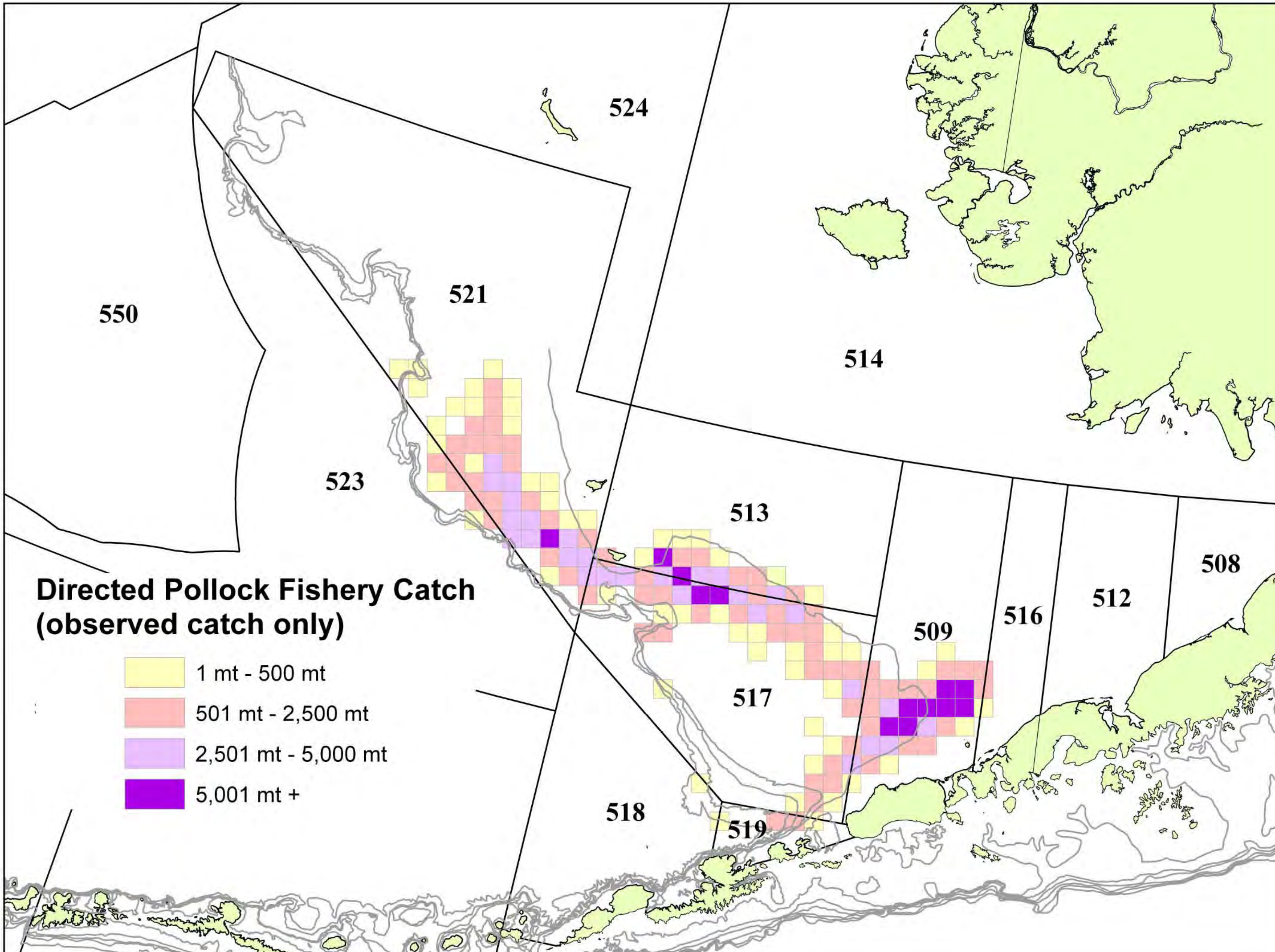
500 mt - 2,500 mt
2,500 mt - 5,000 mt
5,000 mt +



Directed Pollock Fishery Catch
(observed catch only)
1 mt - 500 mt
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2,501 mt - 5,000 mt
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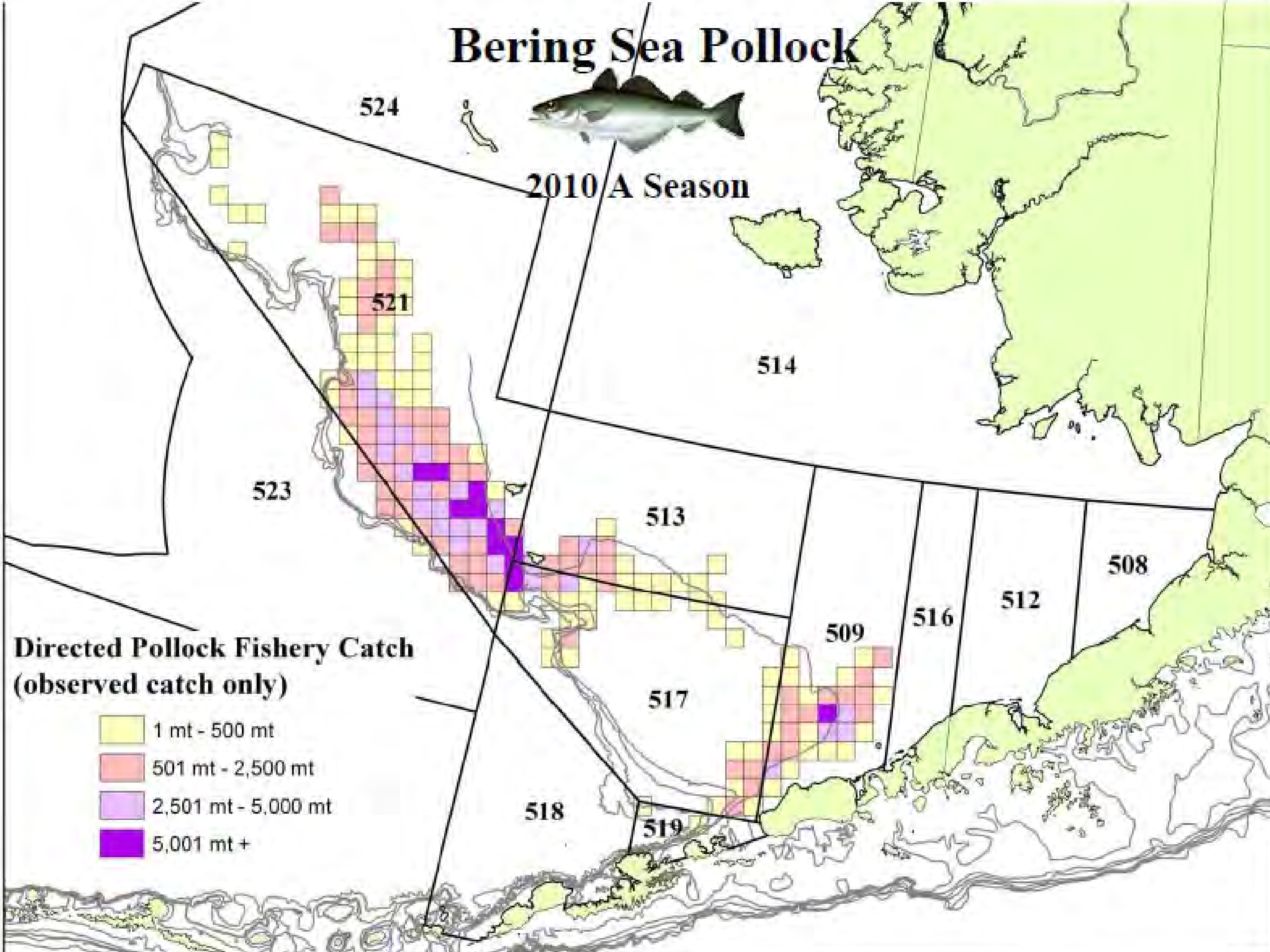
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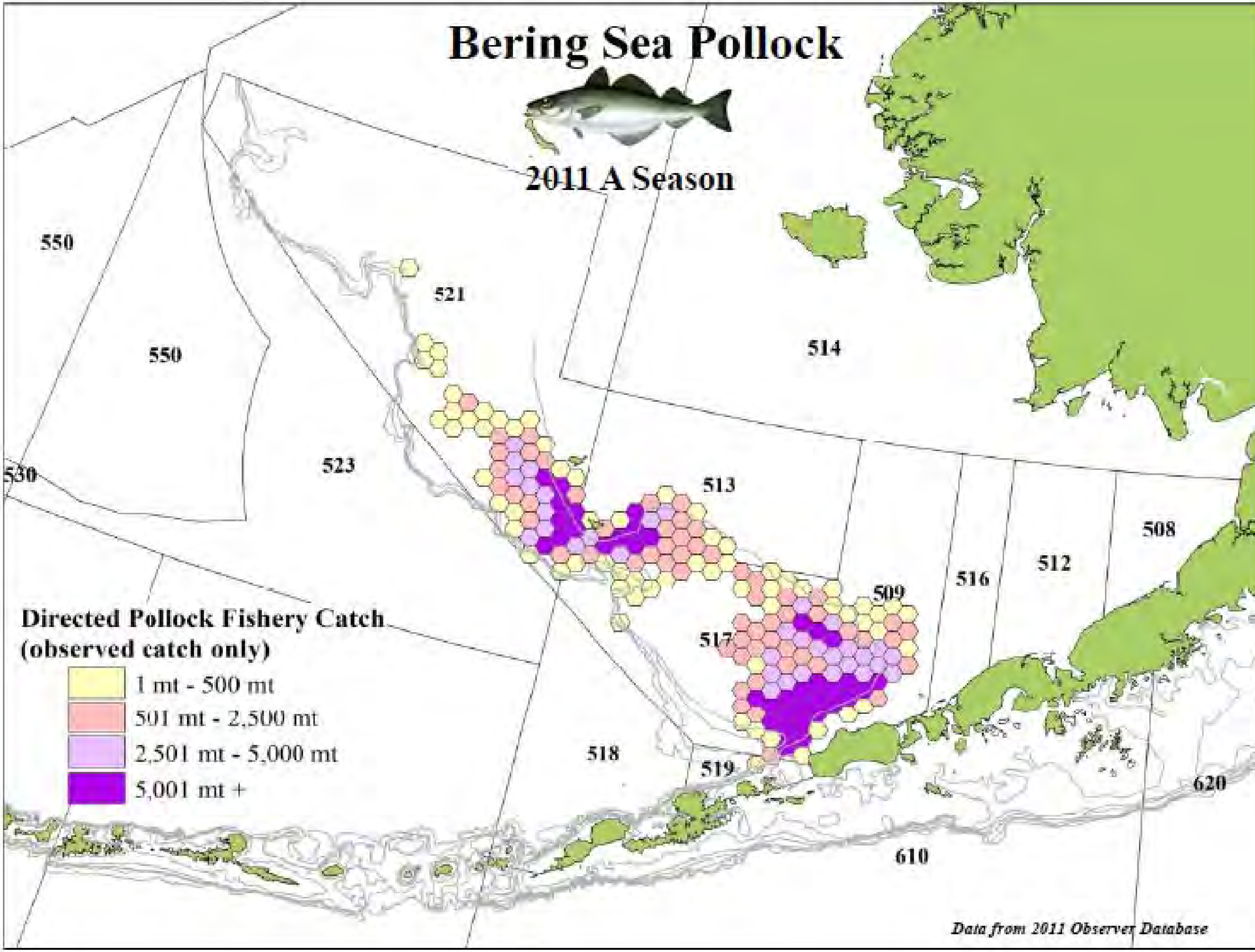
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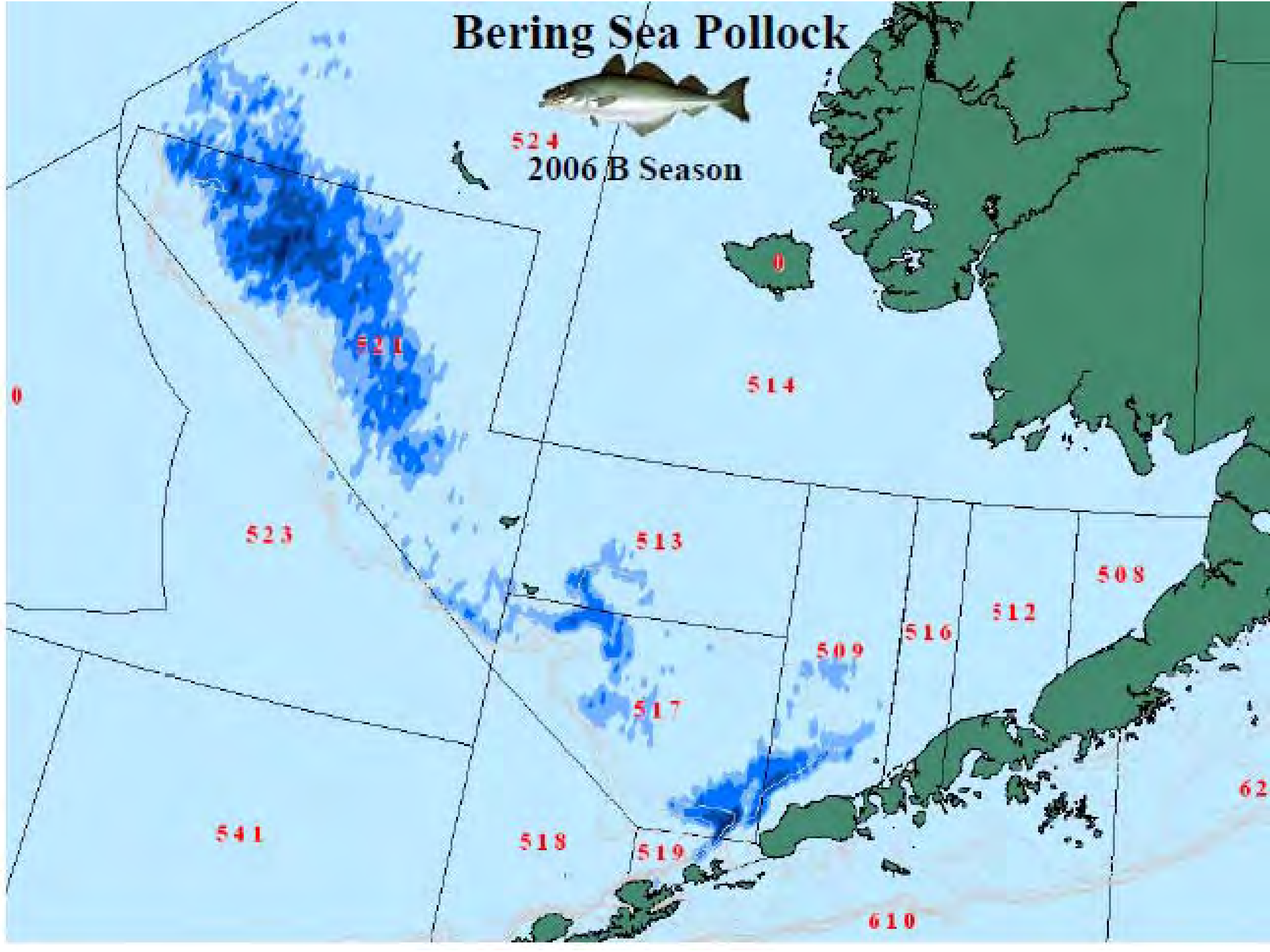
Data from 2011 Observer Database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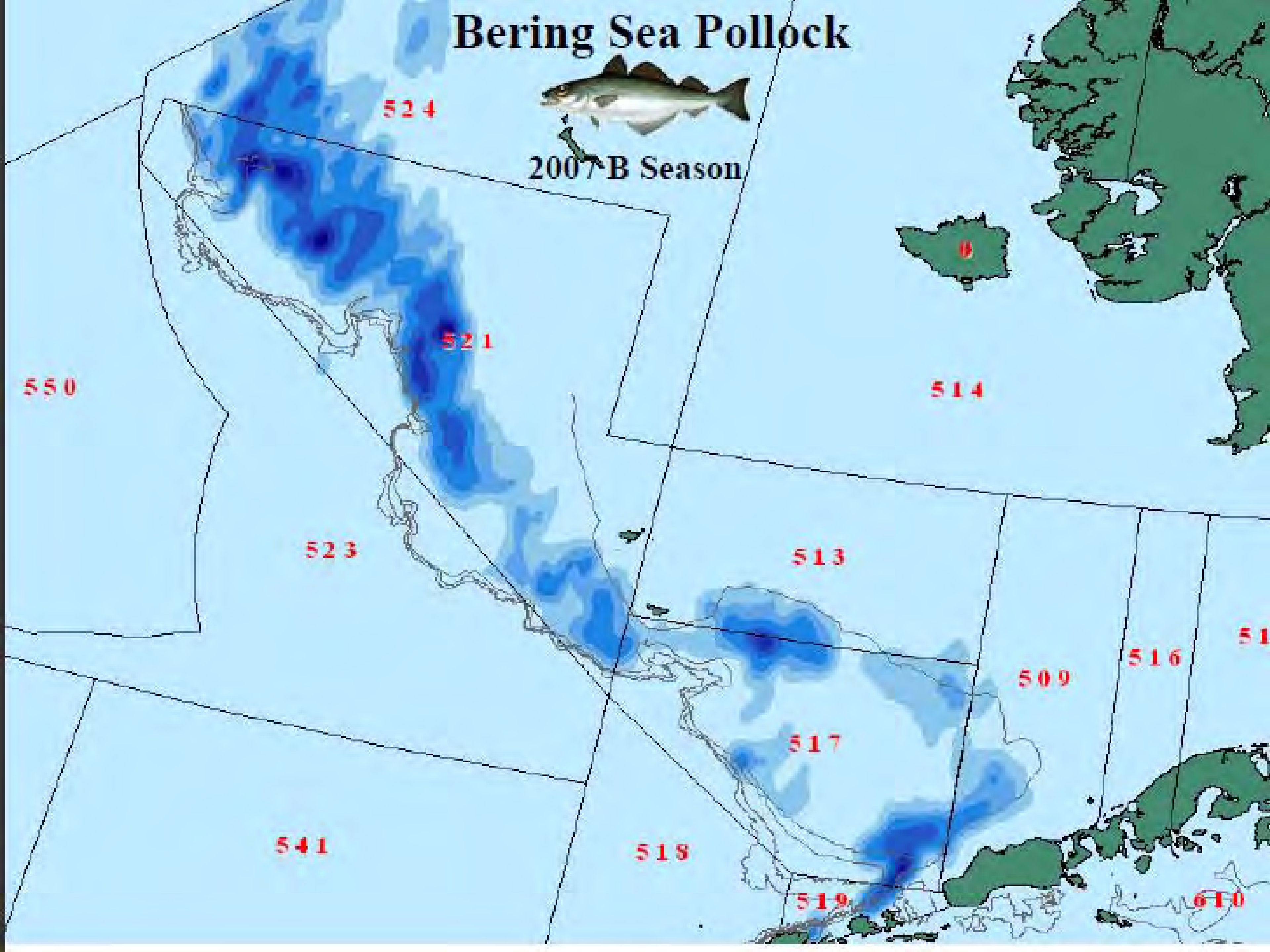
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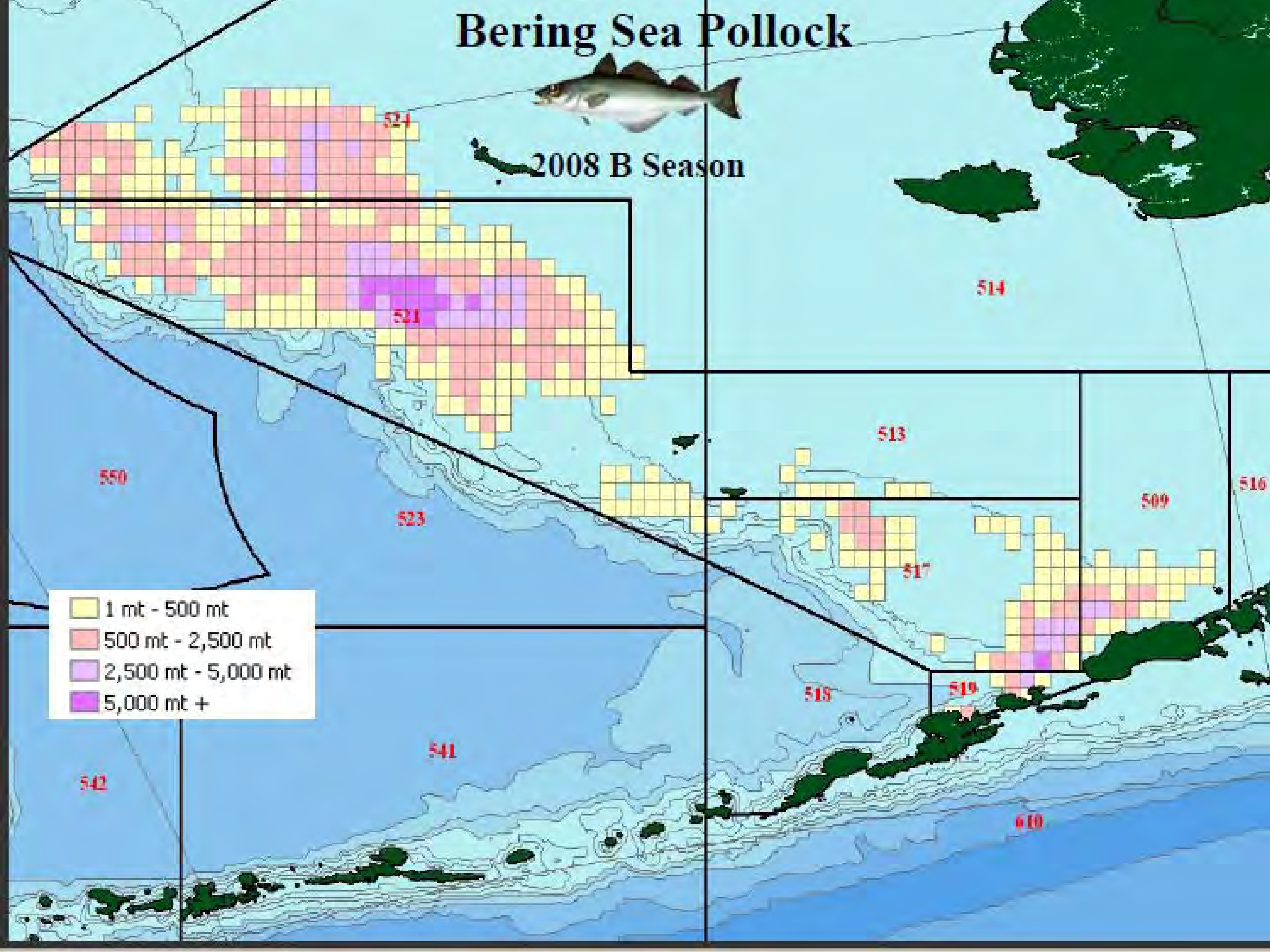
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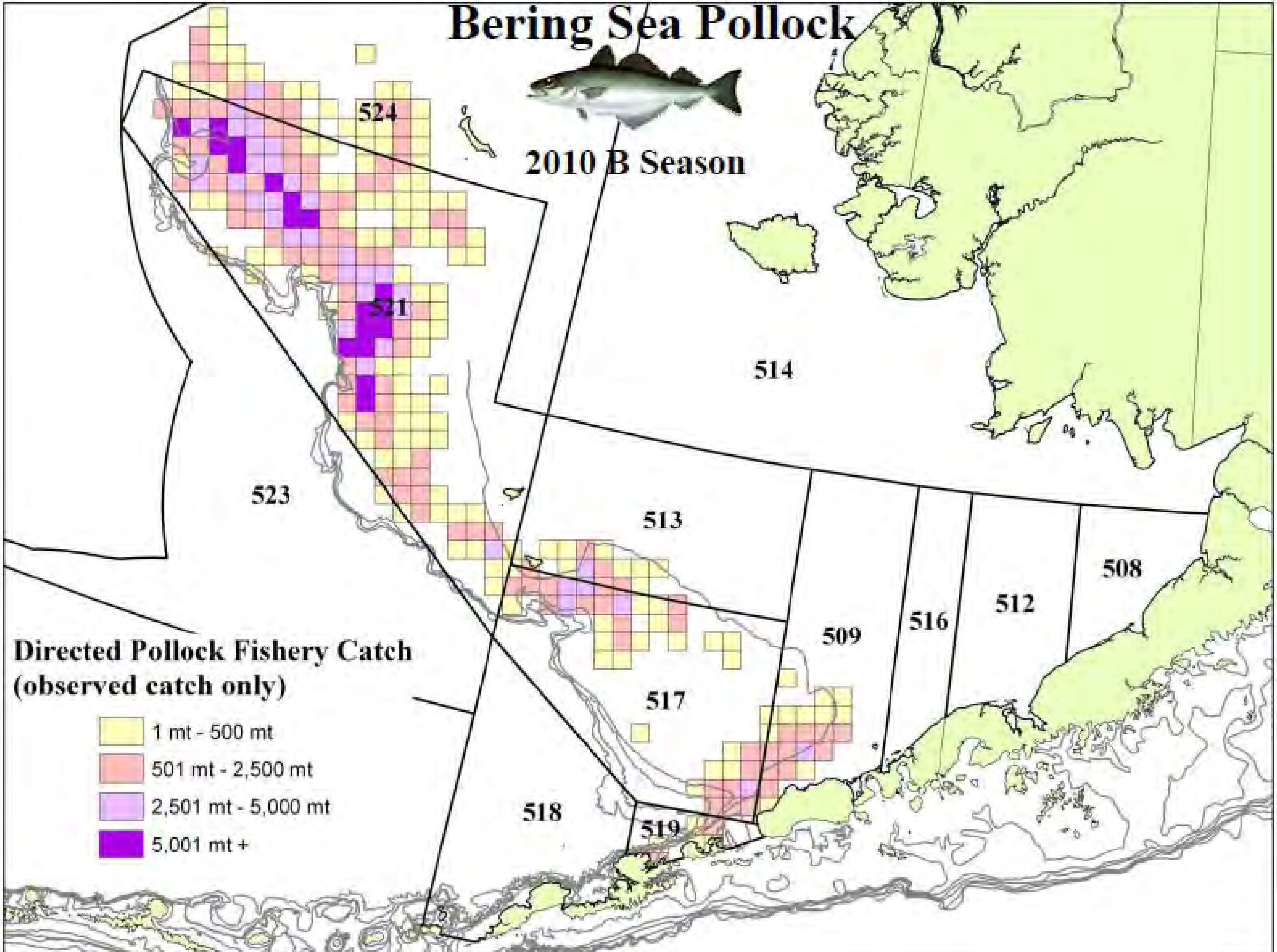

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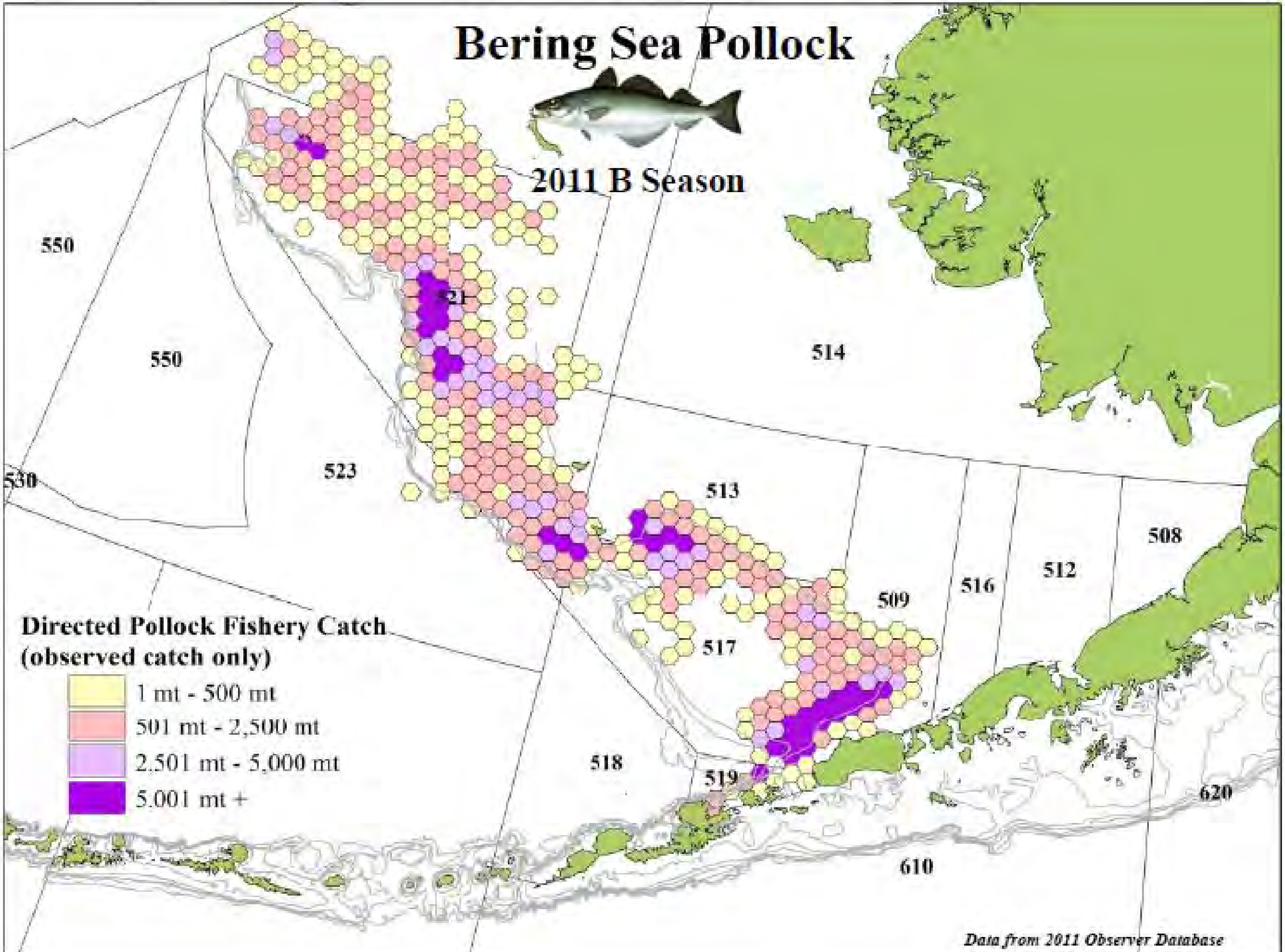
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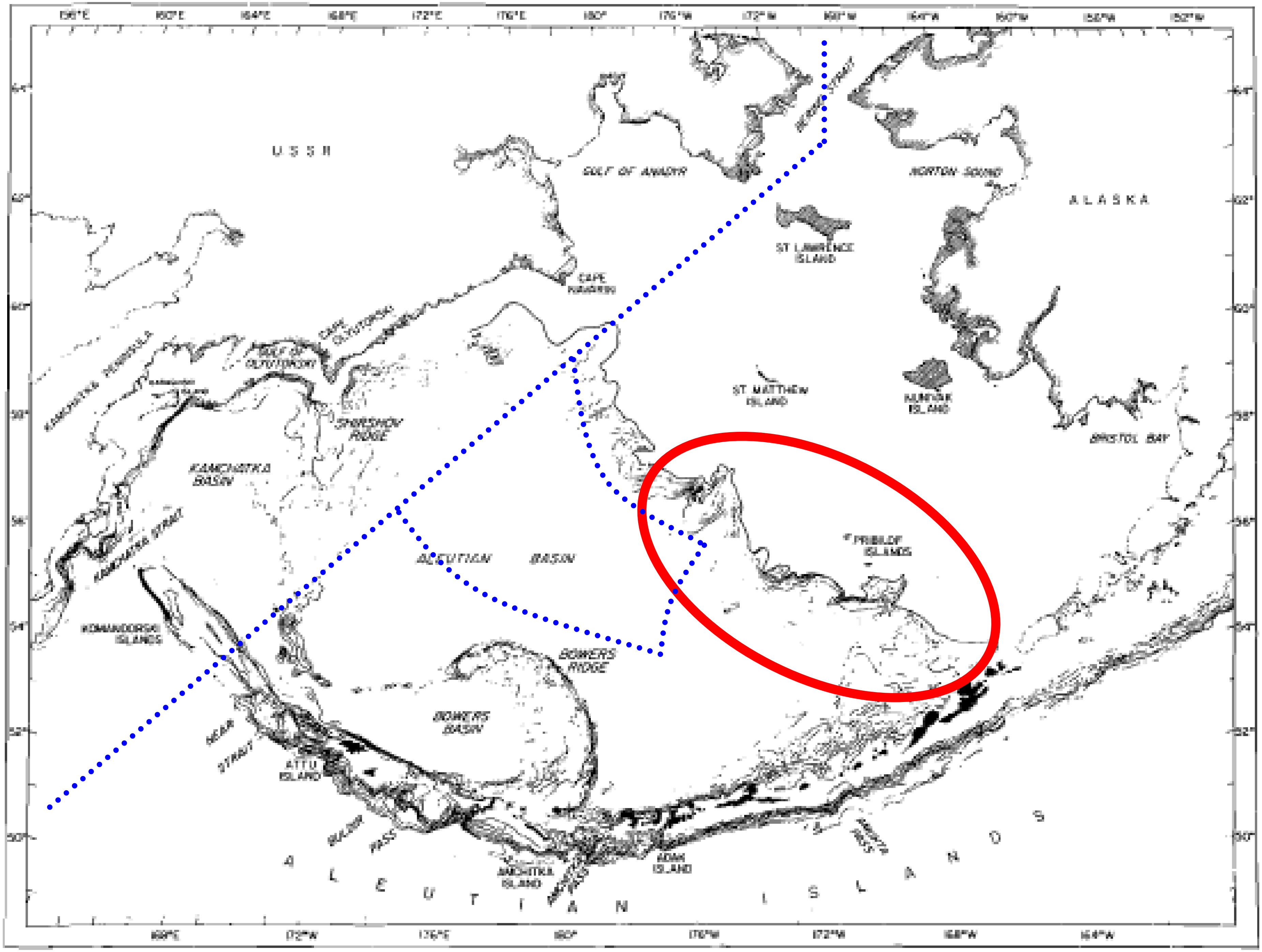
U S S R
GULF OF ANADYR
NORTON SOUND
ALASKA
ST LAWRENCE ISLAND
CAPE NAVARIN
CAPE OLYUTORSKI
GULF OF OLYUTORSKI
KAMCHATKA PENINSULA
ST MATTHEW ISLAND
NUNIVAK ISLAND
SHIRSHOV RIDGE
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PRIBILOF ISLANDS
ALEUTIAN BASIN
KOMANDORSKI ISLANDS
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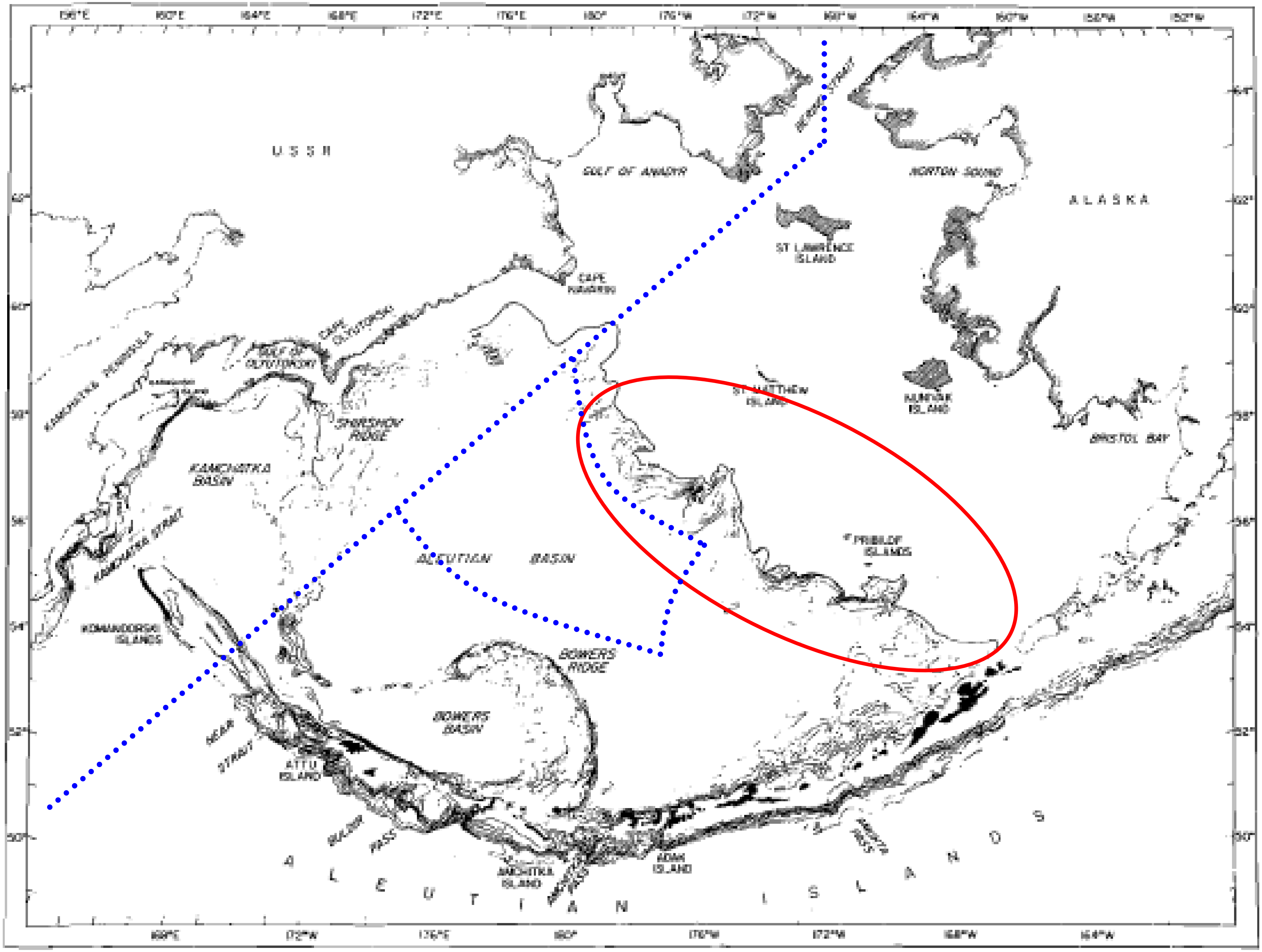
ADAK ISLAND
ALEUTIAN ISLANDS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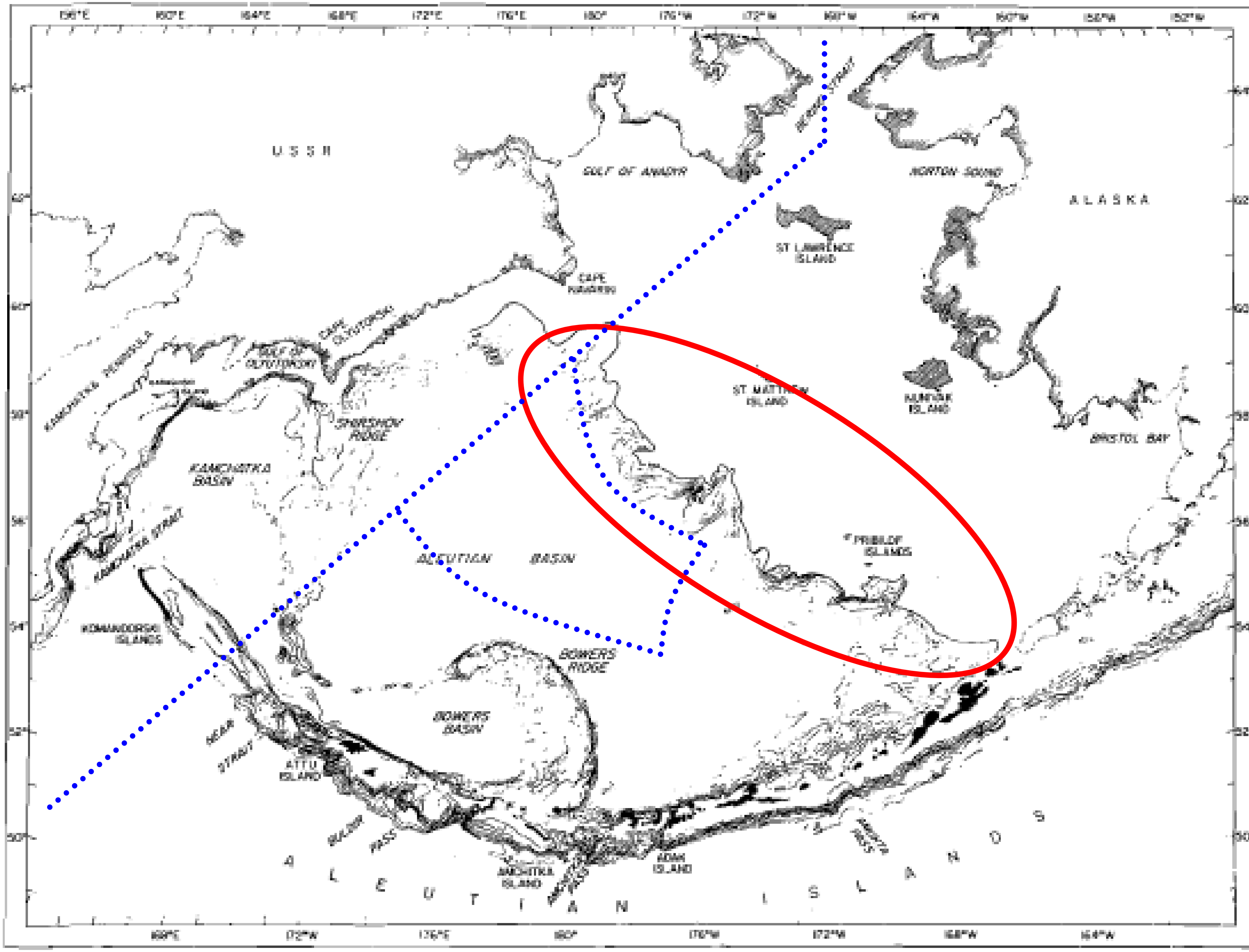
USSR
GULF OF ANADYR
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CAPE OLYUTORSKI
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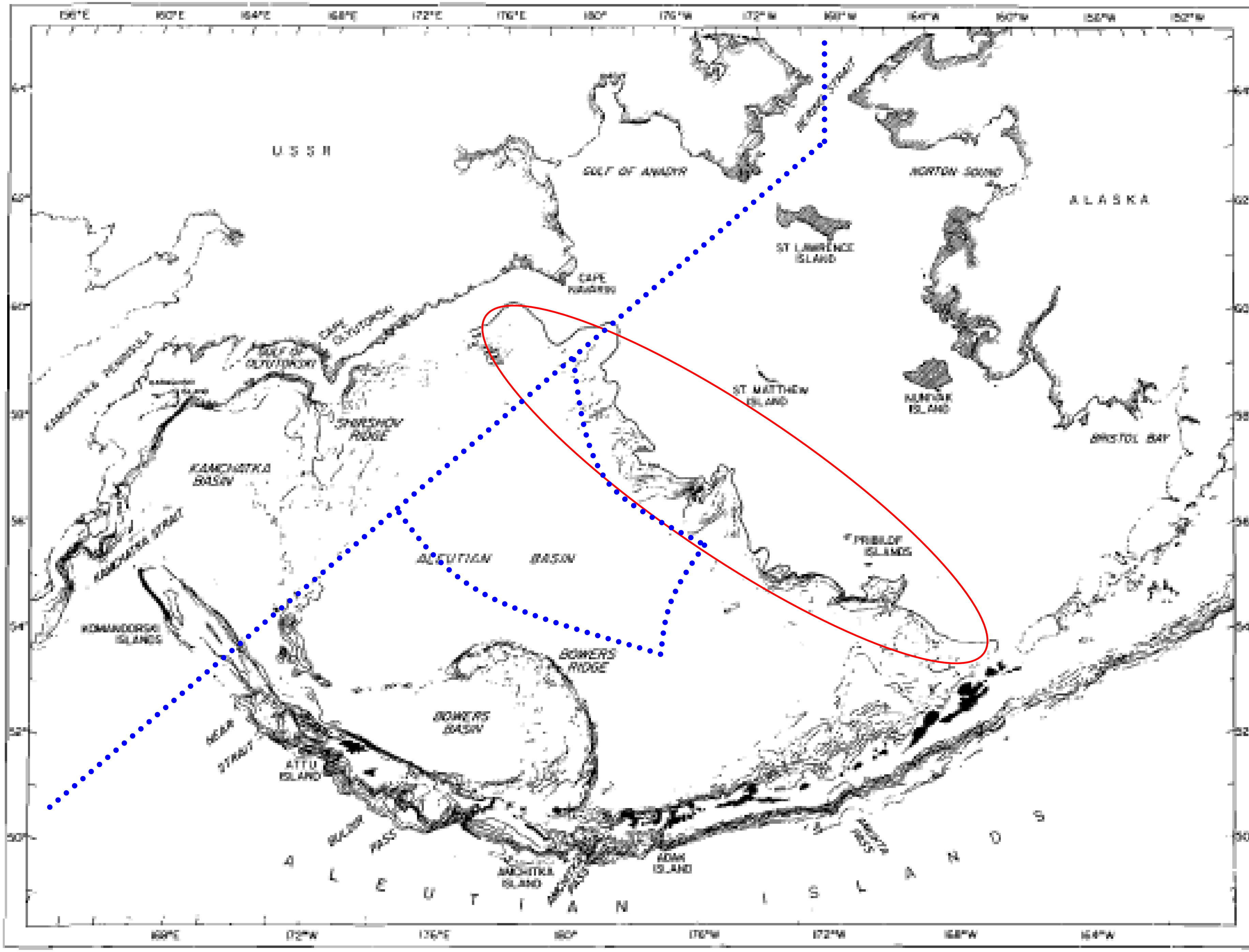
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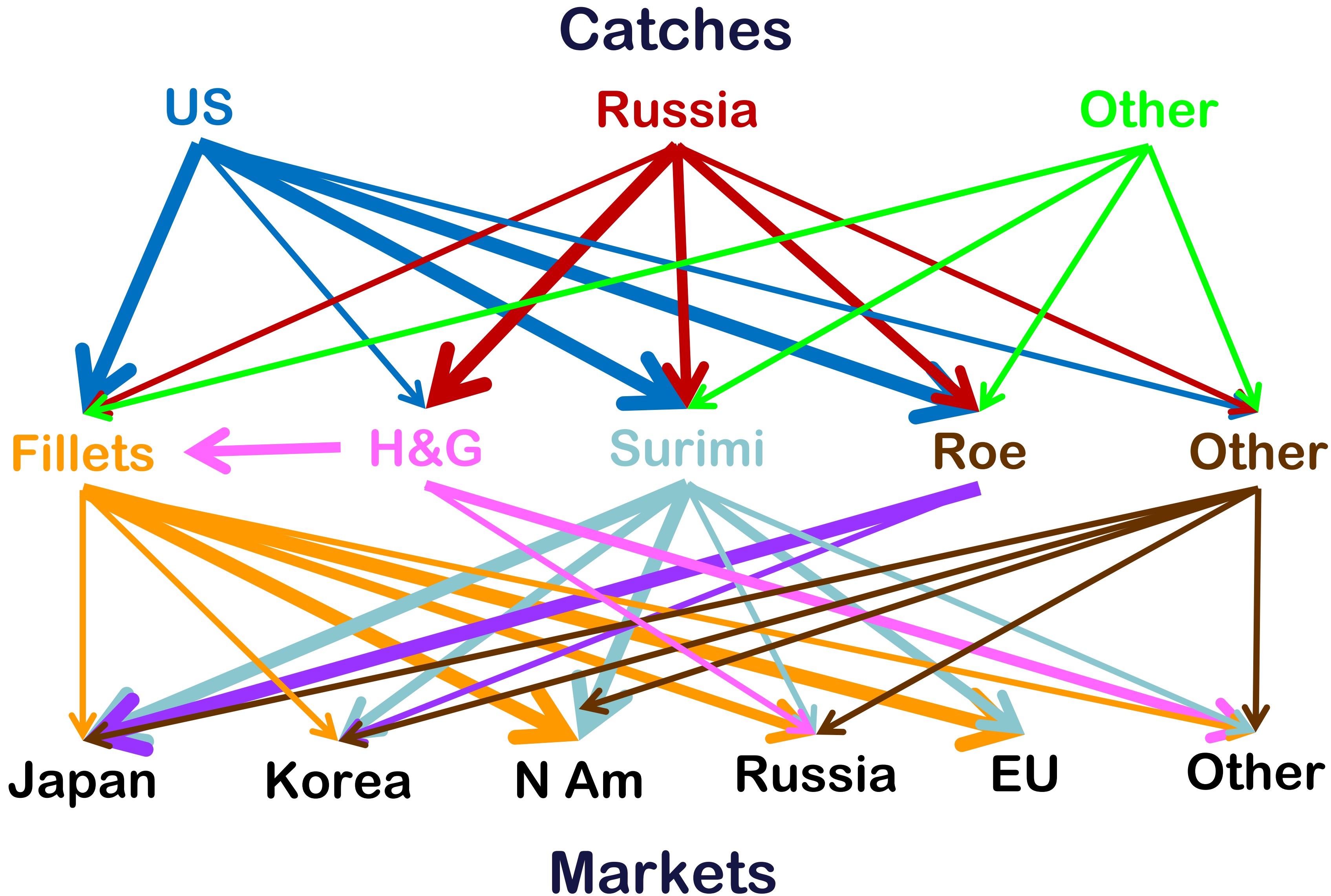
Eastern Bering Sea Pollock—An Integrated Market



Bioeconomic Game with Two Regions with a Shared Stock and Interdependent Markets—Cooperative Solution

$$max\left(\mathrm{EU}\right) = \sum_{t=0}^{\infty} g\left(\mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{h}_{1,t}, \mathbf{h}_{2,t}, r_1, r_2, \eta_1, \eta_2\right)$$

$$\begin{pmatrix} \mathbf{h}_{1,t} \\ \mathbf{h}_{2,t} \end{pmatrix} = f'\begin{pmatrix} \mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{X}_{1,t-1}, \mathbf{X}_{2,t-1}, \\ \mathbf{Y}_{1,t-1}, \mathbf{Y}_{2,t-1}, \mathbf{Z}_{1,t-1}, \mathbf{Z}_{2,t-1} \end{pmatrix} + \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{pmatrix}$$

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Bioeconomic Game with Two Regions with a Shared Stock and Interdependent Markets—Cooperative Solution

$$\max \mathscr{L} = \sum_{t=0}^{\infty} g\left(\mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{h}_{1,t}, \mathbf{h}_{2,t}, r_1, r_2, \eta_1, \eta_2\right) +$$

$$\begin{pmatrix} \boldsymbol{\lambda}_{1,t} \\ \boldsymbol{\lambda}_{1,t} \end{pmatrix} \left(\begin{pmatrix} \mathbf{h}_{1,t} \\ \mathbf{h}_{2,t} \end{pmatrix} - f'\begin{pmatrix} \mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{X}_{1,t-1}, \mathbf{X}_{2,t-1}, \\ \mathbf{Y}_{1,t-1}, \mathbf{Y}_{2,t-1}, \mathbf{Z}_{1,t-1}, \mathbf{Z}_{2,t-1} \end{pmatrix} - \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{pmatrix} \right)$$

Solve for derivatives w.r.t. each variable; set them equal to zero and solve the resulting system of nonlinear equalities for the optimum values; check second order conditions.

A Bioeconomic Game with Two Regions, a Shared Stock and Independent Input and Output Markets—Cooperative Solution

$$max(\mathrm{EU}) = \sum_{t=0}^{\infty} g_1\left(\mathbf{X}_t, \mathbf{h}_{1,t}, r_1, \eta_1\right) + \sum_{t=0}^{\infty} g_2\left(\mathbf{X}_t, \mathbf{h}_{2,t}, r_2, \eta_2\right)$$

$$\begin{pmatrix} \mathbf{h}_{1,t} \\ \mathbf{h}_{2,t} \end{pmatrix} = f'\left(\mathbf{X}_t, \mathbf{X}_{t-1}, \mathbf{Y}_{t-1}, \mathbf{Z}_{t-1}\right) + \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{pmatrix}$$

The optimal solution for this specification is not the same as the optimal solution when the stocks are independent.

A Bioeconomic Game with Two Regions, Independent Stocks, but Integrated Input or Output Markets—Cooperative Solution

$$max\left(\mathrm{EU}\right)=\sum_{t=0}^{\infty} g\left(\mathbf{X}_{1,t},\mathbf{X}_{2,t},\mathbf{h}_{1,t},\mathbf{h}_{2,t},r_1,r_2,\eta_1,\eta_2\right)$$

$$\mathbf{h}_{1,t} = f_1'\left(\mathbf{X}_{1,t},\mathbf{X}_{1,t-1},\mathbf{Y}_{1,t-1},\mathbf{Z}_{1,t-1}\right)+\boldsymbol{\varepsilon}_{1,t}$$

$$\mathbf{h}_{2,t} = f_2'\left(\mathbf{X}_{2,t},\mathbf{X}_{2,t-1},\mathbf{Y}_{2,t-1},\mathbf{Z}_{2,t-1}\right)+\boldsymbol{\varepsilon}_{2,t}$$

The optimal solution for this specification is not the same as the optimal solution when input and output markets are independent.

Solutions to Two-Party Games

At present, the U.S. and Russia adopt harvest management strategies that ignore the strategies adopted by one another –we do our thing, they do their thing, and we both pretend that it does not matter that we are harvesting a stock that diffuses across the convention line.

While this may be a feasible strategy if the extent of transboundary exchange is small, it could be infeasible if the exchanges are substantial.

Photo: USCG

Solutions to Two-Party Games

Under a cooperative strategy, the US and Russia would agree to a joint management strategy that maximizes total utility of harvests based on operating efficiencies and market advantages; concerns about the distribution of benefits between nations could be addressed through side-payments, e.g., royalties. To maximize joint profits, the U.S. and Russia would seek to exercise monopoly power in product markets.

Solutions to Two-Party Games

Cournot-Nash equilibria, Stackleberg equilibria, and Stackleberg disequilibria represent strategies under which each party recognize that it’s benefits are conditional on the other’s choices but where the parties stop short of maximizing their joint product.

In the case of Bering Sea pollock, these solutions represent a recognition that there are biological and market externalities associated with independently adopted harvest management strategies and that the optimal choice of a management strategy for the US EEZ pollock fishery will depend on the management strategy that the Russian Federation adopts and vice versa.

Musings

Governance and industrial organization of the US pollock fishery differs markedly from the governance and industrial organization of Russian Federation EEZ pollock fisheries.

Since 1999, the US fishery has operated under a rights-based governance structure that has allowed firms to form cooperatives to contractually sub-allocate shares of the total allowable catch (TAC) to individual vessels thereby greatly increasing profitability and investment in caapital and technological innovation.

Musings

While the US EEZ pollock fishery has become highly capitalized, profitable, and geared to value-added production, conditions in the Russian Far East have not been as conducive to investment needed to modernize fishing or processing capital.

Musings

The lack of investment in modern processing technology means that the same volume of fish harvested in Russian Federation EEZ waters yields a lower quality and lesser quantity of product than it would yield if harvested by current U.S. vessels.

These effects are exacerbated to the extent that the portion of the eastern Bering Sea pollock stock that distributes into the Russian EEZ consists of disproportionate numbers of younger fish.

Take-Home

- Straddling stocks subject to discordant management regimes produce suboptimal levels of socioecological benefits.
- Coordinated management of straddling stocks is particularly difficult when:
  - the stock is migratory, the spatial distribution of the stock varies, or biomass and recruitment are highly variable or uncertain;
  - management/social objectives, risk aversion, time preferences, or expectations about future access to the stock differ; or
  - product prices, input costs, or access to capital are variable, uncertain, or differ.

Take-Home

Inter alia, the optimal strategy will depend on:

- stock abundance and stock distribution,
- the relative value of product (roe, surimi, fillet),
- product recovery rates,
- differences in the magnitude of harvesting and processing costs,
- the enforceability of catch limits at fishery and individual participant levels, and
- the character of governance regimes.


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