MANAGING NORTHERN BALTIC SALMON FISHERIES UNDER SOCIAL-ECOLOGICAL COMPLEXITY

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Introduction to the conflict between sequential salmon fisheries

Description of the bioeconomic model

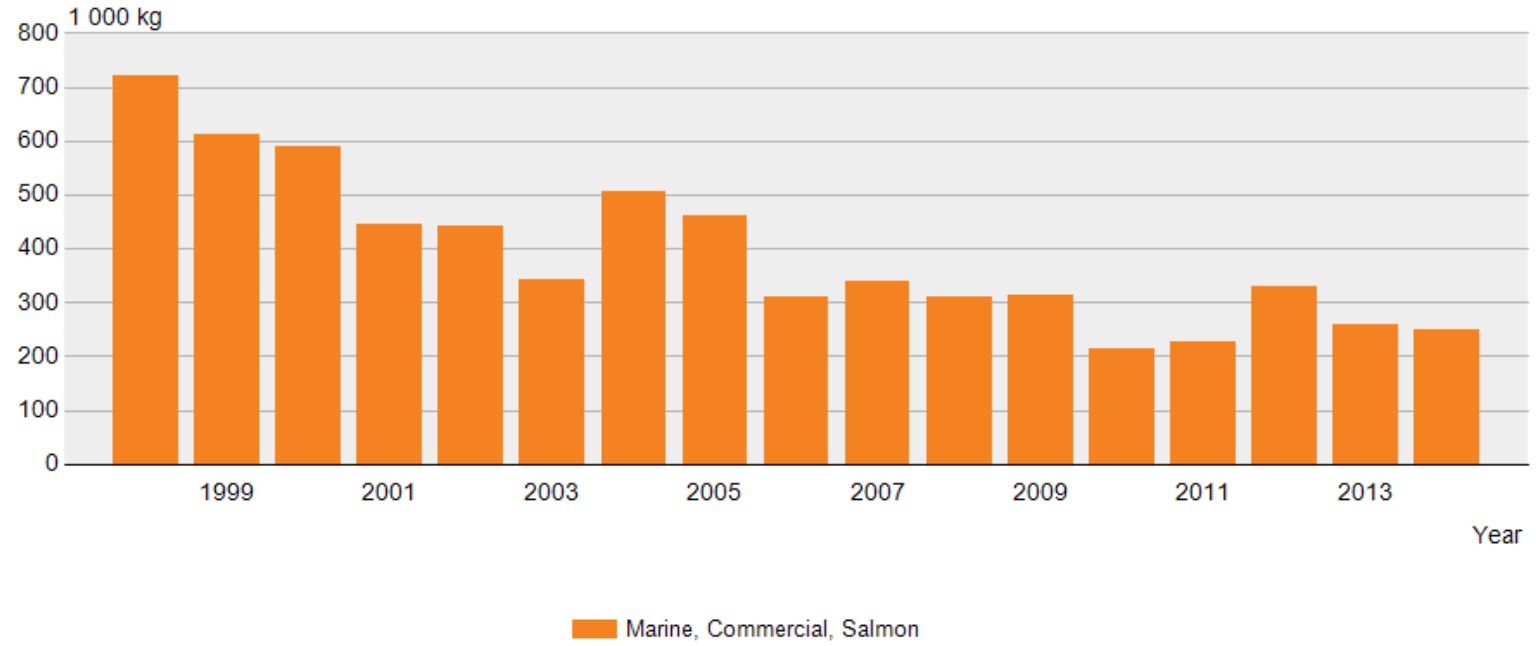
Ecological and economic implications of ignoring behavioral complexity of anglers

THE MIGRATION ROUTES AND FISHERIES OF RIVER TORNIONJOKI SALMON STOCK

→ Migration routes △ Trap net fishery ● Recreational fishery ■ Longline fishery

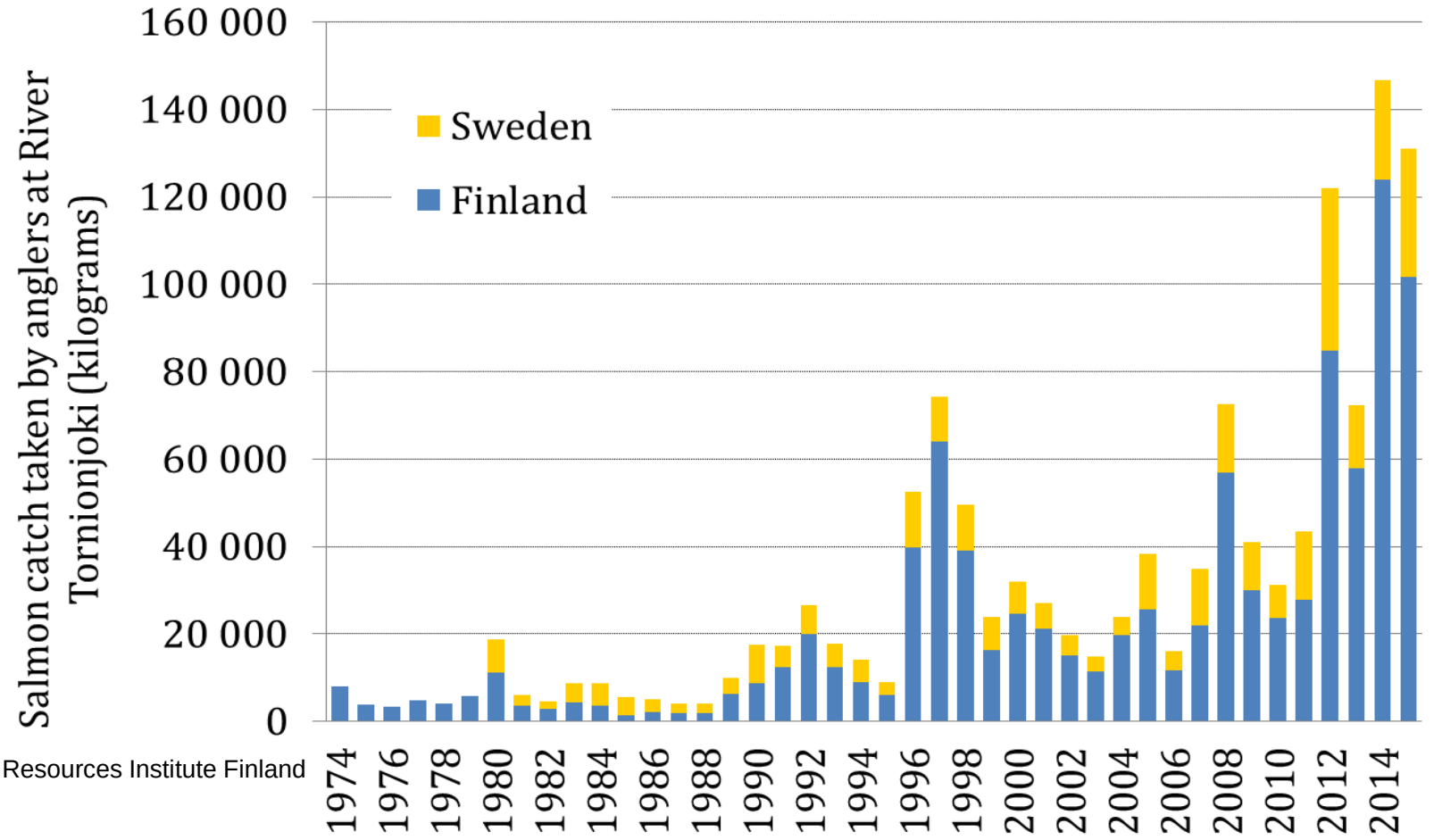
COMMERCIAL SALMON FISHERY IN DECLINE

Finnish marine commercial salmon catch



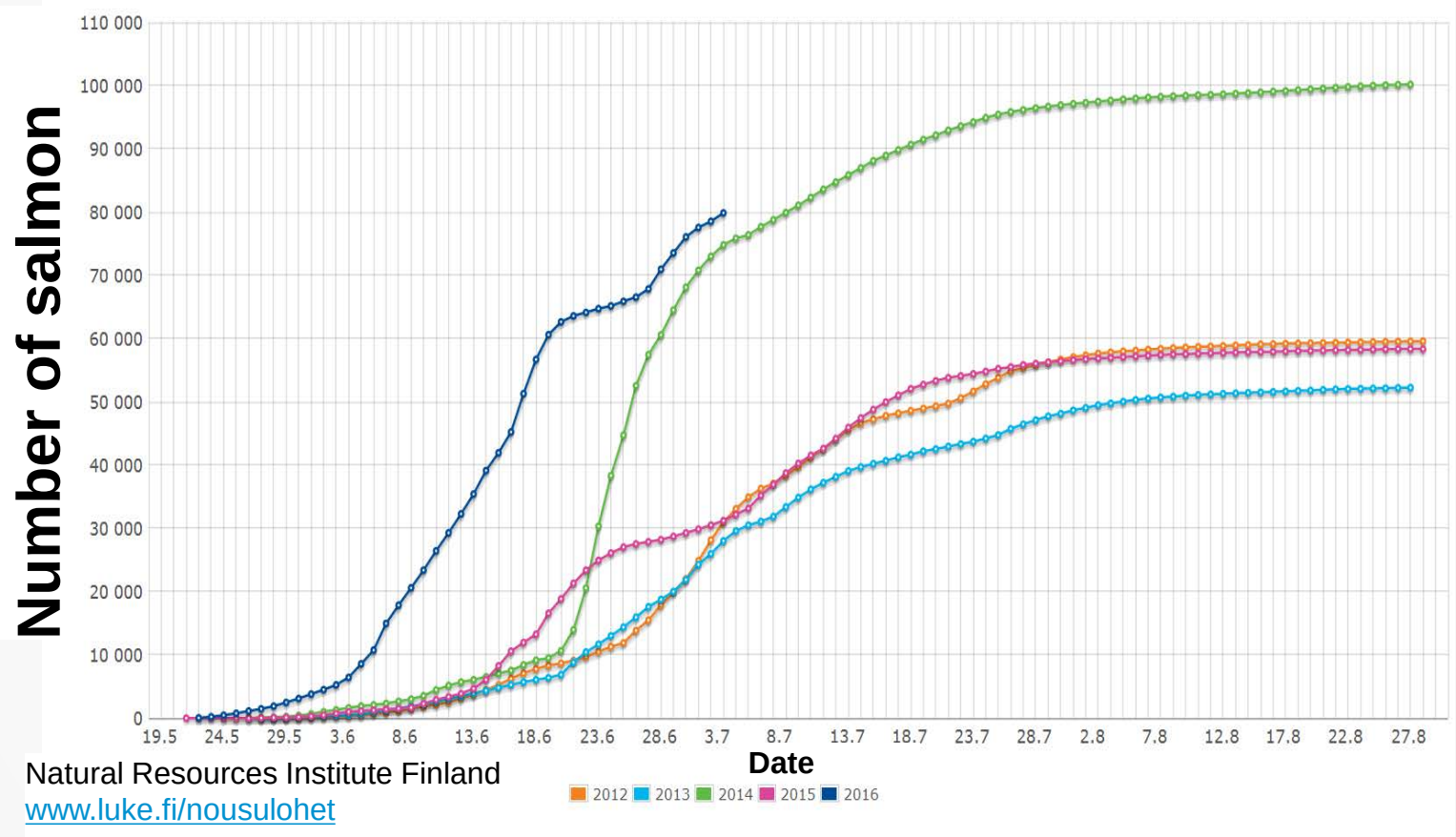
Source: Natural Resources Institute Finland, Fishery total

SALMON ANGLING GAINS POPULARITY



Source: Natural Resources Institute Finland

SALMON SPAWNING RUN



Natural Resources Institute Finland
www.luke.fi/nousulohet

COASTAL VS. RECREATIONAL FISHERY

How the optimal management of the commercial fishery depends on the recreational fishery?

What are the implications of ignoring angling and the behavioral complexity of angling?

THE BIOECONOMIC MODEL

Salmon age-structured population dynamics

Discounted net present value of salmon coastal fishery

Anglers update number of trips and their type: Effort and catch oriented anglers

Satisfaction per angling trip

Stay home or go fishing

Direct effect: Commercial effort decreases the fish available for anglers

Indirect effect: Angling effort decreases the number of spawners

MODEL SPECIFICATIONS

Age-structured population model

- Leslie matrix model with 10 age-classes
- Beverton-Holt stock-recruitment relationship

Optimized commercial trap-net fishery

- Commercial fishermen are profit maximizers
- Dynamic optimization is used to define the commercial effort through time

Recreational fishery

- Type-specific utilities based on valuation studies
- Anglers decide whether to stay home or go fishing based on the satisfaction of previous angling trip
- Socialization defines the frequenzy of angler types through time

SOCIAL COMPLEXITY

ATTRIBUTES OF

1. EFFORT ORIENTED ANGLERS

- Enjoy the nature
- Strong preference for solitude

2. CATCH ORIENTED ANGLERS

- Prefer to catch something
- Slight preference for solitude

SCENARIOS

1. **No recreational fishing**

   A hypothetical scenario to see what is the optimal level of commercial effort when there is no angling

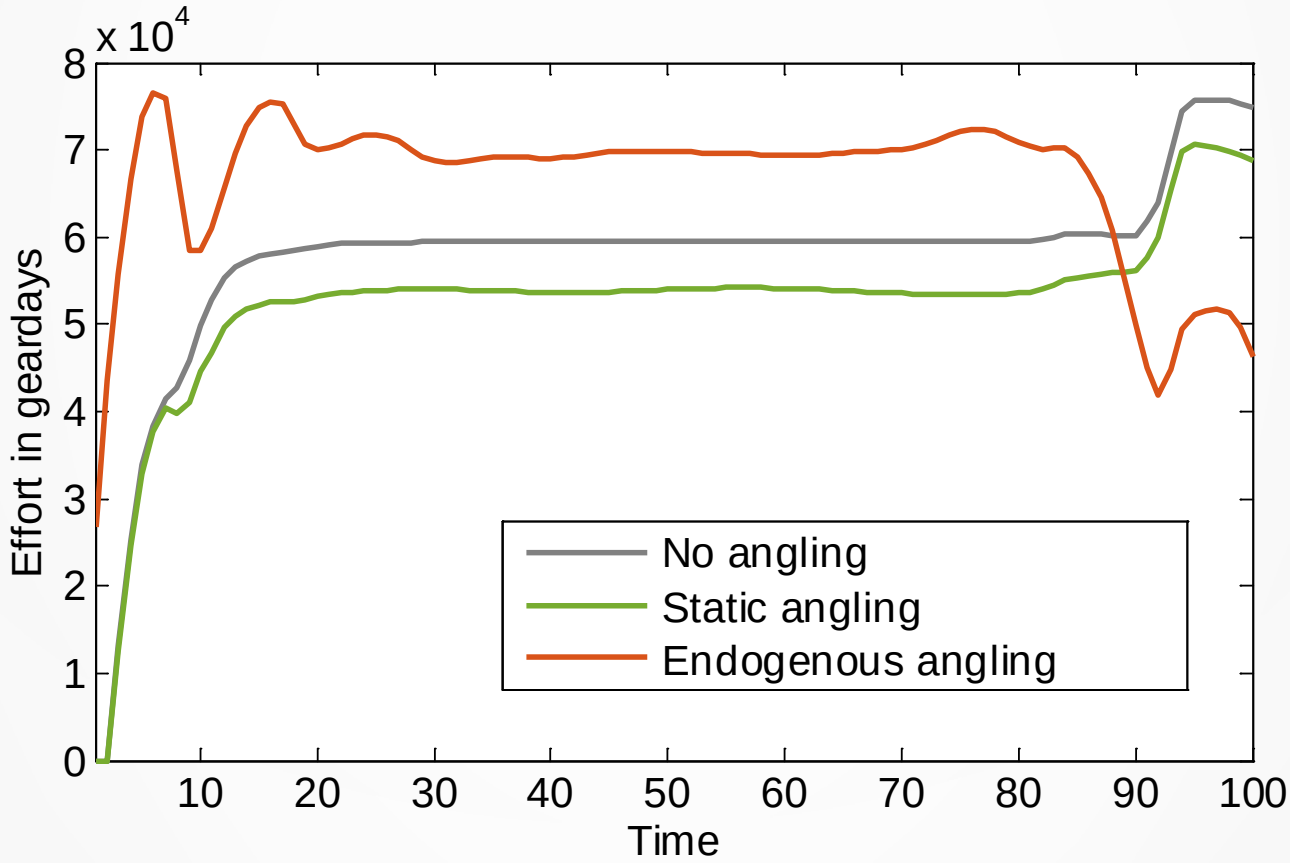
2. **Static recreational fishing**

   A scenario that mimics the current ICES salmon assessment model, where recreational fishing is described by a constant mortality

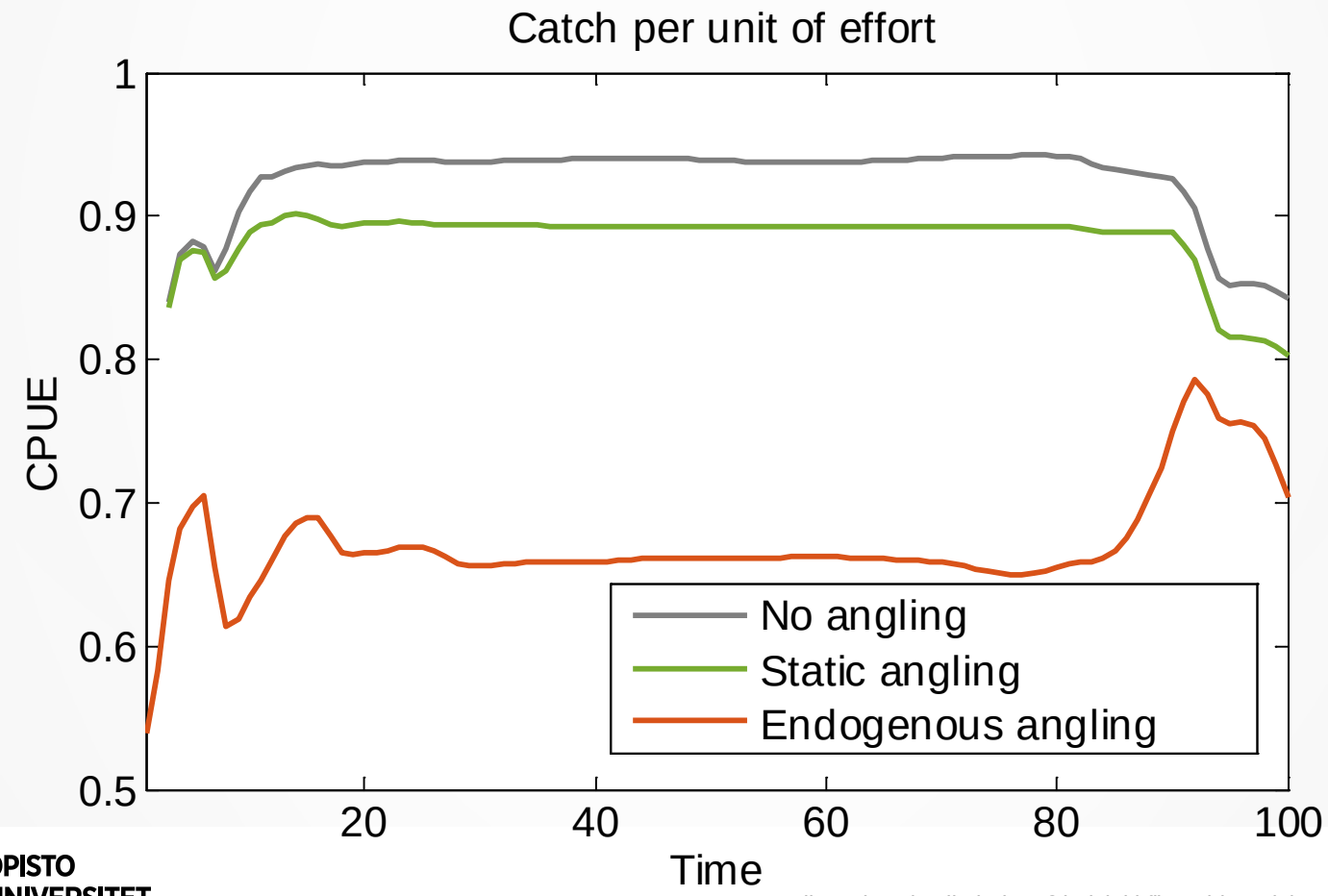
3. **Endogenous recreational fishing with angler behavioral complexity**

   Recreational fishing effort is endogenously changing. Anglers change the frequency of angling trips, dependent on how satisfying each trip is.

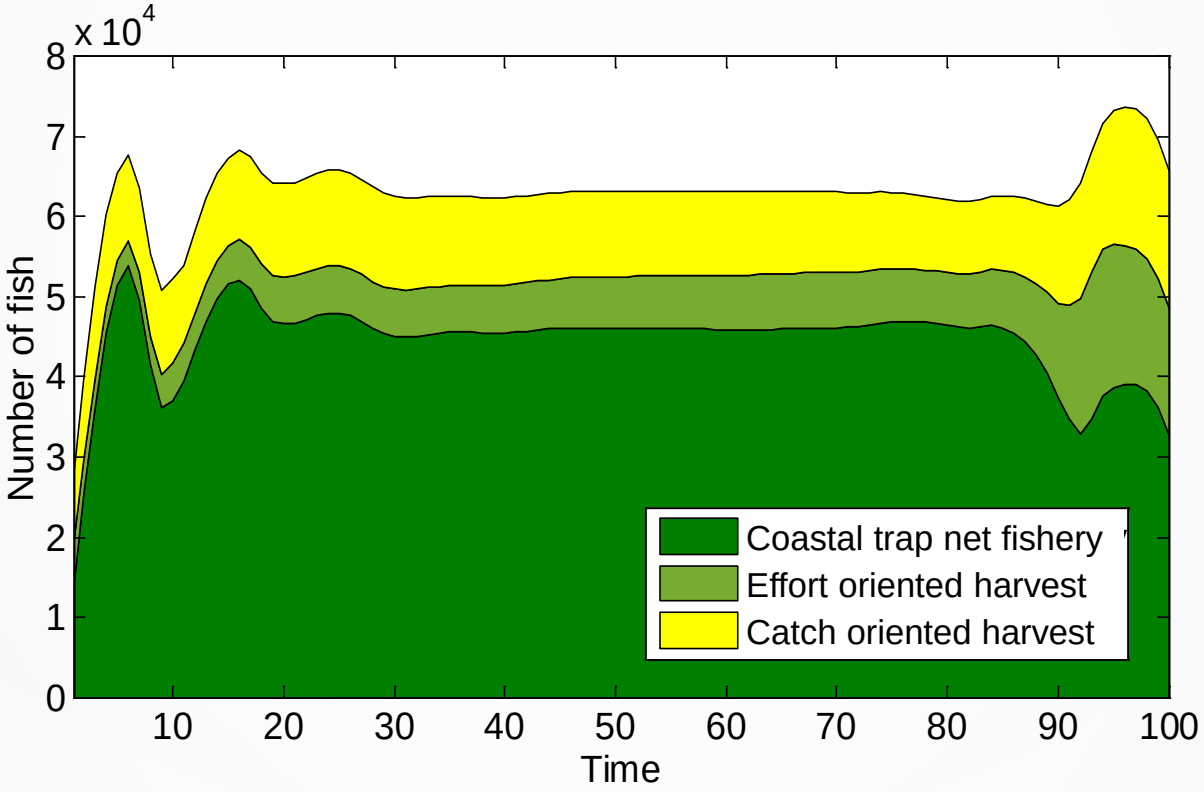
OPTIMAL COMMERCIAL TRAP NET EFFORT



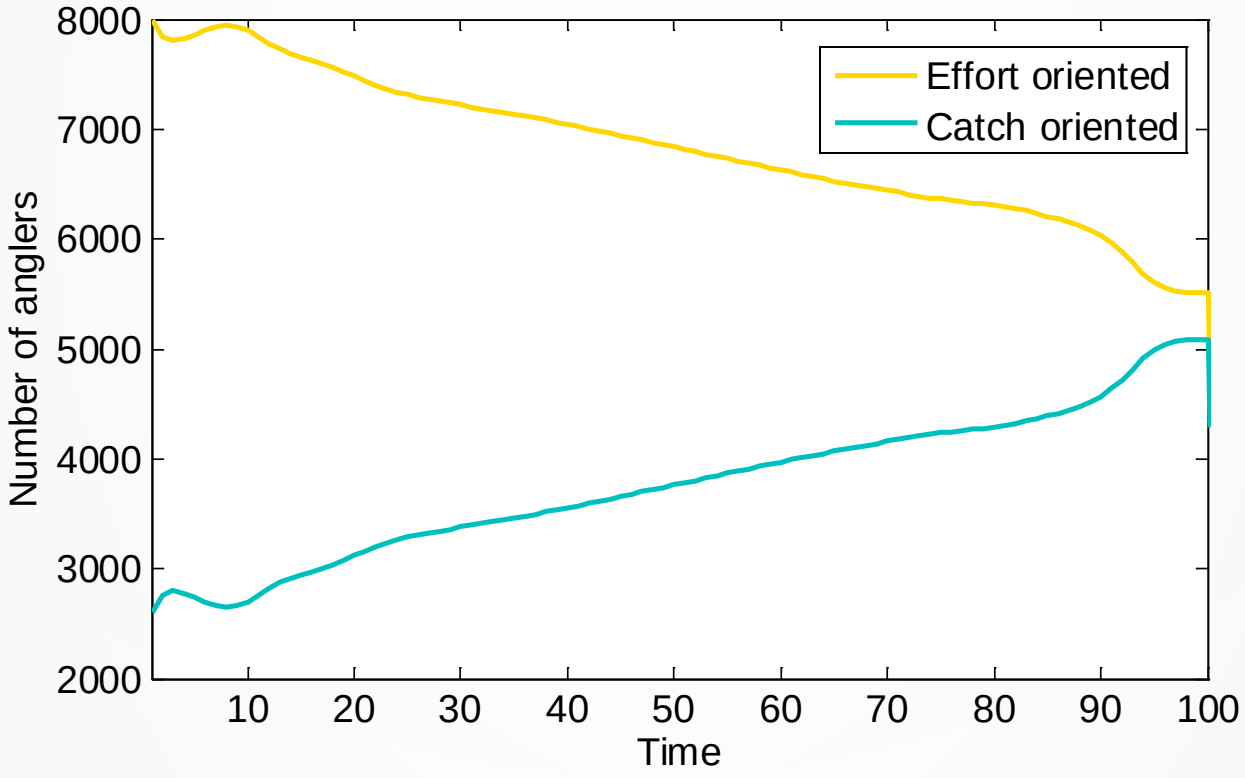
COMMERCIAL FISHERY: CATCH PER UNIT OF EFFORT



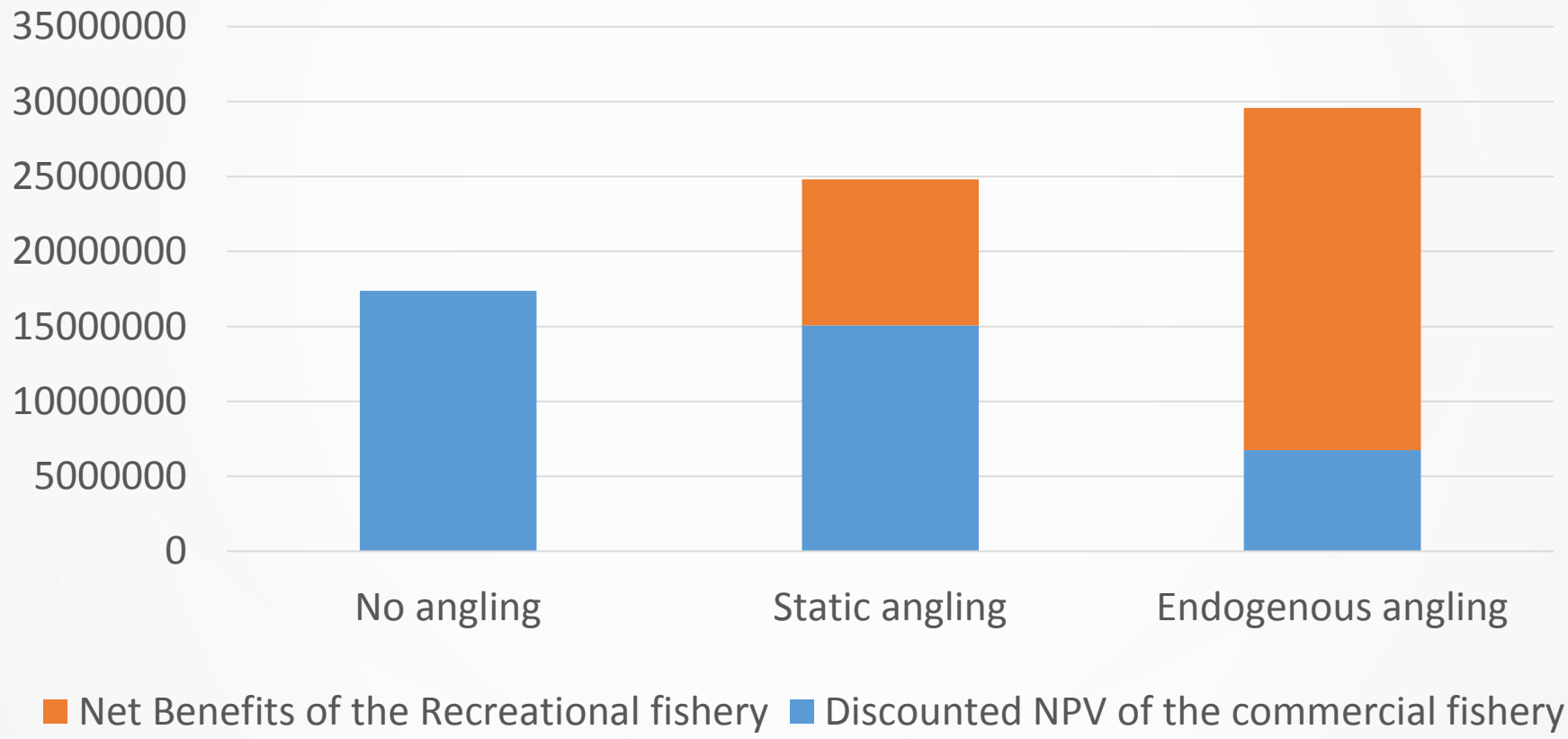
ENDOGENOUS ANGLING: HARVEST



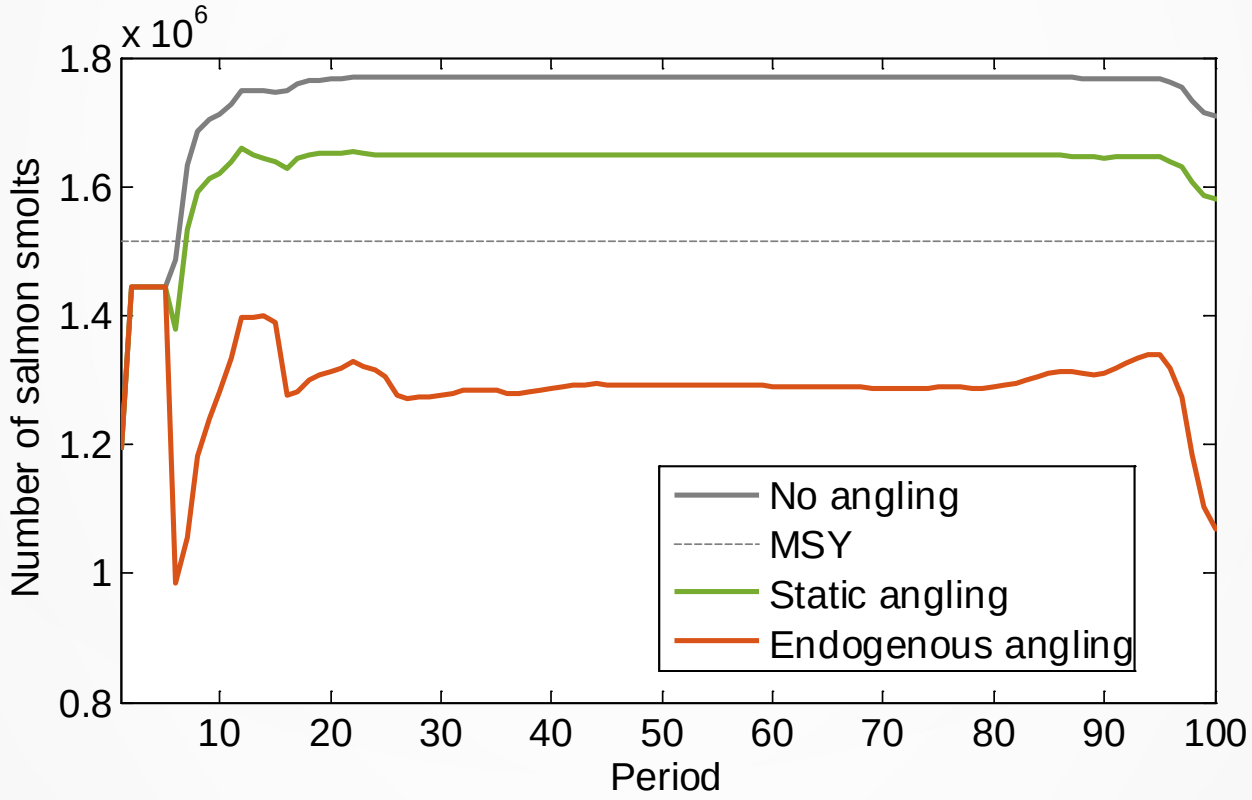
ENDOGENOUS ANGLING: NUMBER OF ANGLERS



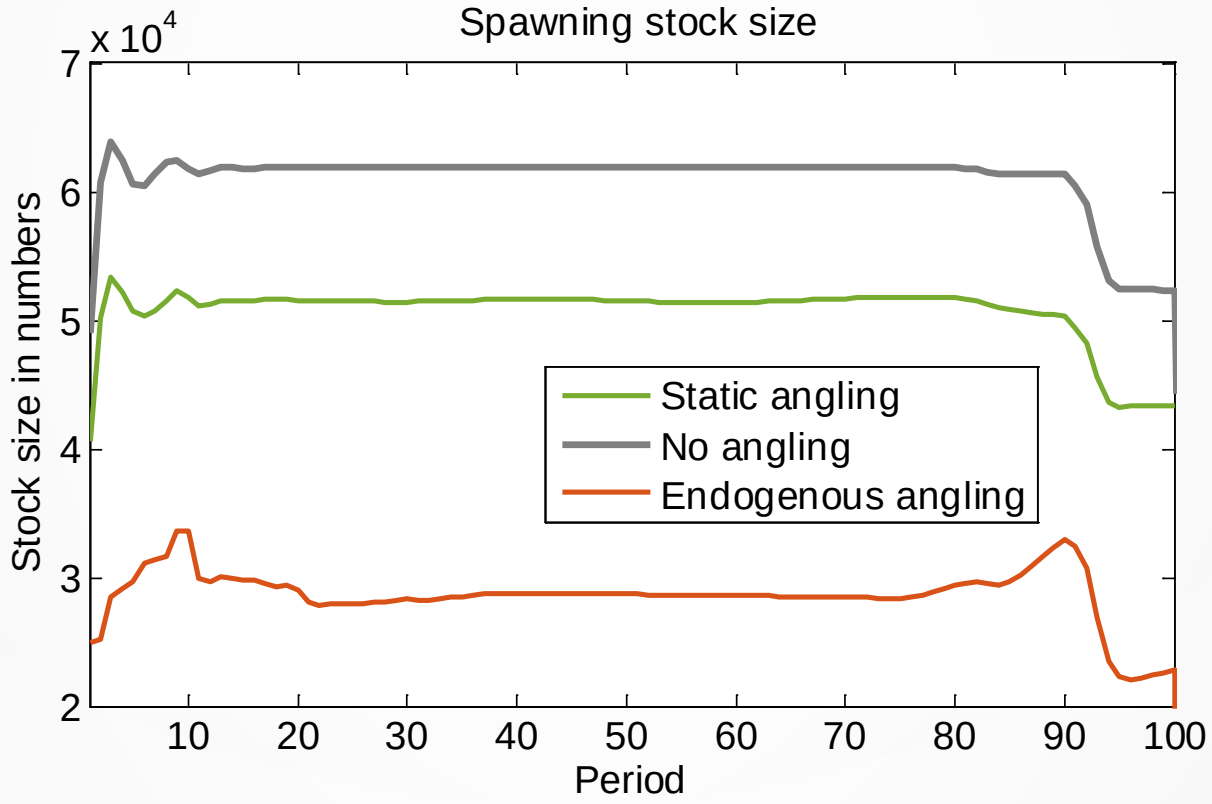
ECONOMIC VALUE OF THE FISHERY



NUMBER OF SALMON SMOLTS



SALMON SPAWNING STOCK SIZE



CONCLUSIONS

- Summed economic value is greatest under endogenous angling scenario
- Surprisingly, the highest commercial effort is realized in the Case 3 under complex angler behavior.
- This is a result of strong competition between the commercial and recreational fishery.
- When the utility of staying at home is low, it is possible that the fish stock crashes as the number of effort oriented anglers increase

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THANK YOU

SALMON POPULATION MODEL

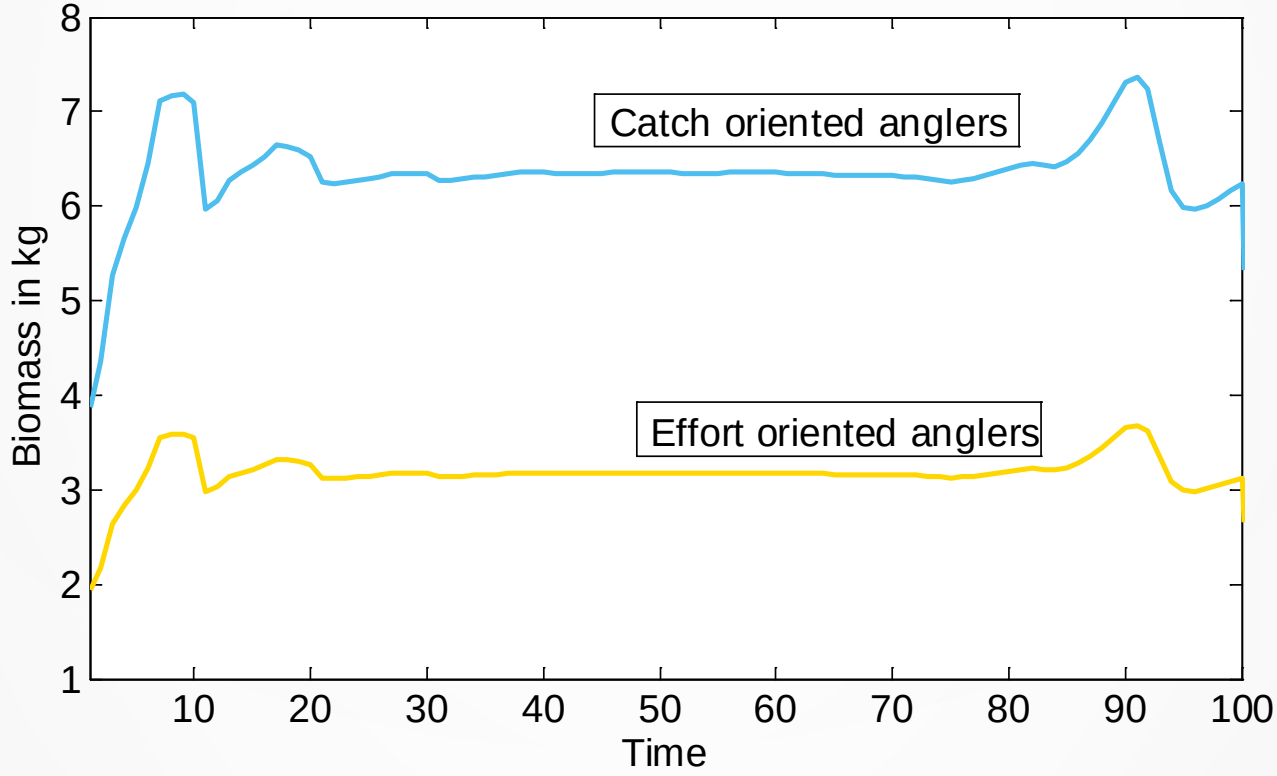
Salmon population
10 age classes

Data provided by ICES Baltic Salmon and Trout Assessment Working Group (WGBAST 2016).

$$s_{i,t+1} = s_{i,t} A_t$$
$$i \in \{1, \ldots, 10\}$$

$$\underbrace{\begin{pmatrix} s_{1,t+1} \\ s_{2,t+1} \\ \vdots \\ s_{i-1,t+1} \\ s_{i,t+1} \end{pmatrix}}_{\boldsymbol{s_{i,t+1}}} = \underbrace{\begin{pmatrix} s_{1,t} \\ s_{2,t} \\ \vdots \\ s_{i-1,t} \\ s_{i,t} \end{pmatrix}}_{\boldsymbol{s_{i,t}}} \underbrace{\begin{pmatrix} FEC_{1,t} & FEC_{2,t} & \ldots & FEC_{i-1,t} & FEC_{i,t} \\ SUR_{1,t} & 0 & \ldots & 0 & 0 \\ 0 & SUR_{2,t} & \ldots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \ldots & SUR_{i-1,t} & 0 \end{pmatrix}}_{\boldsymbol{A_t}}$$

ENDOGENOUS ANGLING: RECREATIONAL HARVEST PER TRIP



COMMERCIAL COASTAL TRAP NET FISHING

Dynamic optimization of the commercia fishing effort

$$H_{i,t}^{v} = (1 - e^{-q_i E_{v,t}}) h r_i s_{i,t}$$

Catchability; Optimal commercial effort; Homing rate; Number of age i salmon

$$H_{i,t}^{v} \geq 0$$

$$s_{i,t} \geq 0$$

$$\pi_{v,t} = \sum_{i=1}^{10} p_i H_{i,t}^{v} g - c E_{v,t}$$

Price; Gutting parameter; Cost of unit of effort

$$NPV_v = \max_{E_{v,t}} \sum_{t=1}^{50} \pi_{v,t} / (1 + r)^{t-1}$$

ANGLER DECISION MAKING

- There are a types of anglers: effort (denoted by f) and catch oriented (denoted by c).

Effort per angler ($e_{a,t}$) is the number of fishing days ($n_{a,t}$) multiplied by fishing motivation ($\varepsilon_{a,t}$):

$$e_{a,t} = \varepsilon_{a,t} n_{a,t}$$

Total type-specific effort depends on the number of anglers ($N_{a,t}$) and the effort of single angler ($e_{a,t}$):

$$E_{a,t} = e_{a,t} N_{a,t}$$

ANGLER DECISION MAKING

Total recreational effort:

$$E_{tot,t} = E_{c,t} + E_{f,t}$$

Total recreational harvest in number of fish, summed over all salmon age-classes:

$$H_{i,t}^{R,tot} = hr_i s_{i,t} \overbrace{e^{-q_i E_{v,t}}}^{\text{Escapement from commercial fishery}} \overbrace{(1 - e^{-qR_i E_{tot,t}})}^{\text{Recreational fishery harvest rate}}$$

ANGLER DECISION MAKING

Type-specific recreational harvest:

$$H_{i,a,t} = H_{i,t}^{R,tot}\left(\frac{E_{a,t}}{E_{tot,t}}\right)$$

ANGLER DECISION MAKING: Utilities

Utility of catch oriented anglers depends on the number of fish caught per trip

$$U_t^c = \frac{\mu H_t^c - \theta {H_t^c}^2}{e_{c,t}}$$

Utility of effort oriented anglers depends on the weight (W)

$$U_t^f = \frac{\mu W_{i,t}^f + \theta {W_{i,t}^f}^2}{e_{f,t}}$$

ANGLER DECISION MAKING

- Number of angling trips at t+1 ($e_{a,t+1}$) depends on last year's benefits from angling ($U_{a,t}$) and the average utility obtained from leisure ($\widetilde{U}_{a,t}$).

- Average utility obtained from leisure is the result of angling and the exogenous utility from staying home and doing an alternative activity $\bar{U}$.

- Free days per year is given by $\bar{e}$

Should I stay home or should I go fishing?

$$e_{a,t+1} = e_{a,t}\frac{U_{a,t}}{\widetilde{U}_{a,t}}$$

- Discrete version of replicator equation (Sigmund 1986)

$$\widetilde{U}_{a,t} = \frac{e_{a,t}U_{a,t} + \left(\bar{e} - e_{a,t}\right)\bar{U}}{\bar{e}}$$

EVOLUTION OF ANGLER BEHAVIOR

- Total number of anglers is $N_T = N_{f,t} + N_{c,t}$
- Adopting angling as a new hobby: τN_t stop and τN_t start angling
- **Socialization** determines the angler type according to the prevalence of each angler type

$$\frac{e_{f,t}N_{f,t}}{e_{c,t}N_{c,t} + e_{f,t}N_{f,t}} \qquad \frac{e_{c,t}N_{c,t}}{e_{c,t}N_{c,t} + e_{c,t}N_{c,t}}$$

EVOLUTION OF ANGLER BEHAVIOR

- The difference equations of the angler types:

$$N_{f,t+1} = (1-\theta)N_{f,t} + \theta N_T \frac{e_{f,t}N_{f,t}}{e_{c,t}N_{c,t} + e_{f,t}N_{f,t}}$$

$$N_{c,t+1} = (1-\theta)N_{c,t} + \theta N_T \frac{e_{c,t}N_{c,t}}{e_{c,t}N_{c,t} + e_{c,t}N_{c,t}}$$