Derivation of Shadow Price of Sea Turtle Bycatch in Hawaii-based Longline Fisheries: An Input Distance Function Approach

Hui Huang & PingSun Leung
University of Hawaii at Manoa

Interaction Between Hawaii-based Longline Gear and Sea Turtles

- Sea turtle conservation: one of the most important issues facing Hawaii-based longline fisheries

- Swordfish and Mixed-target fishing:
  shallow sets; high rate of turtle capture

- Tuna-target fishing:
  deep sets; relatively less interactions

Turtle Catches by Trip Types, 1991-1999

Land Year	Swordfish	Mixed	Tuna	% of Swordfish and Mixed
1991	44	10	3	94.74%
1992	57	6	2	96.92%
1993	71	3	3	96.10%
1994	61	2	2	96.92%
1995	46	8	9	85.71%
1996	38	40	9	89.66%
1997	12	30	4	91.30%
1998	34	54	10	89.80%
1999	12	58	6	92.11%
1991-1999	375	211	48	92.43%

Source: Observer's Report, Honolulu Laboratory, NMFS (1991-1999)

Longline Fishing Restricted Areas

Area A: 44 N-28N, 168 W-150 W

No Fishing allowed

Area B: 44 N-28 N, 173 E-168 W

& 150 W-137 W

Restricted longline fishing

100% observer coverage

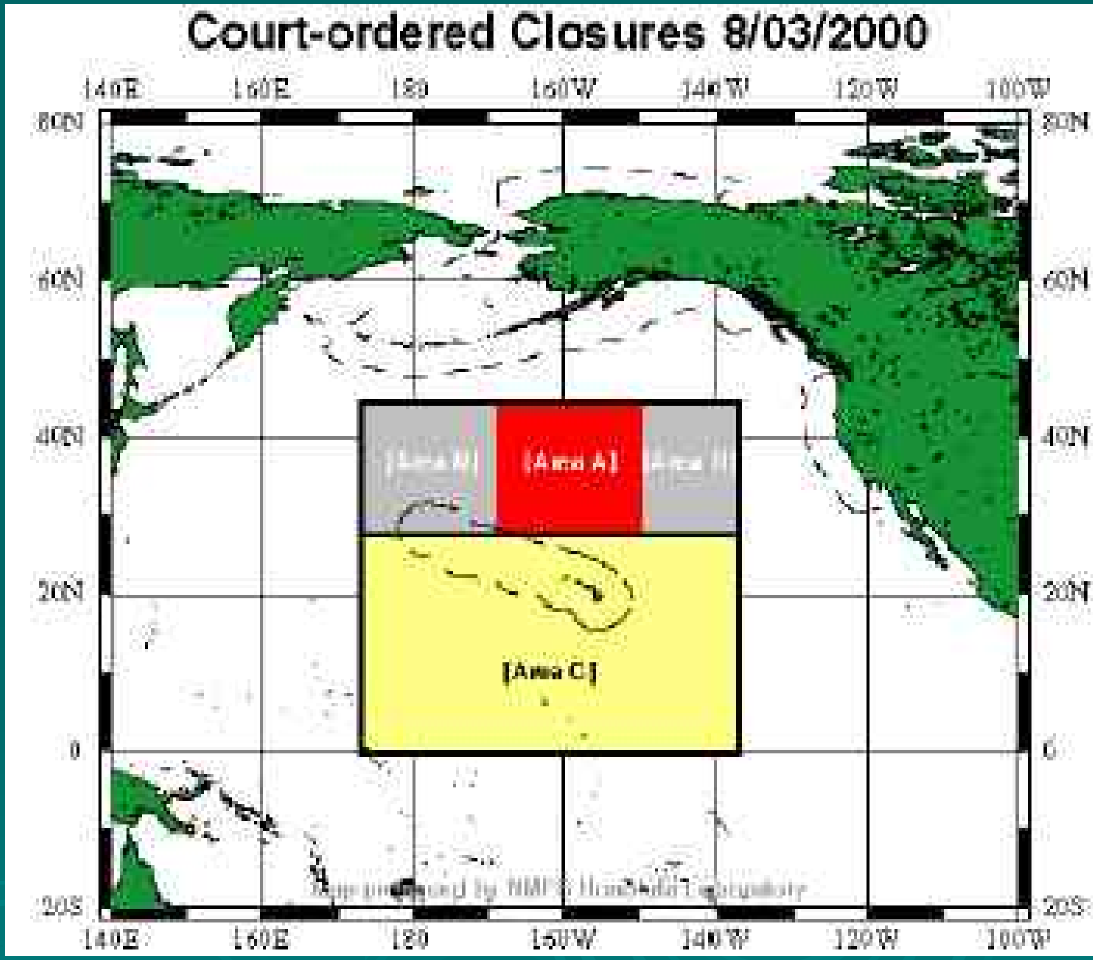
Area C: 28 N-Equator, 173 E-137 W

Only tuna-trip is allowed

Area A : Closed throughout the year

Area B & C: Closed from March 15,

until May 31



Swordfish Ban and Resumption

- 2001, NMFS' preferred alternative:

swordfish-style fishing is prohibited; an area (15-0 North, 145-180 W) is closed for April and May.

- April 2004, Swordfish-style fishing return:

fewer fishing days; observers on board at all times; strict limits on the number of turtles (16 leather-back turtles, 17 loggerhead turtles)

Research Objectives:

- To Introduce an alternative method of calculating cost of sea turtle protection
- To deduce trip-specific shadow price of sea turtle bycatch
- To compare shadow prices of sea turtle bycatch of various periods, locations, and trip types

General idea of the methodology:

- Distance function: used in deducing shadow prices for pollutants (e.g. Fare & Grosskopf, 1993; Cogins and Swinton, 1996)
- General idea: Dual Shephard's lemma yields cost-related shadow prices of undesirable output (sea turtle bycatch) from the input distance function

Previous Studies

- Curtis and Hicks (2000)
- Chakravorty and Nemoto (2000)

  implicit prices of sea turtle bycatch ;

  overall welfare foregone from regulatory policies

Present Work

- No need to specify regulatory constraints
- Modest data requirement
- Flexibility for comparing shadow prices by trip characteristics: time; areas; trip types

Input Distance Function

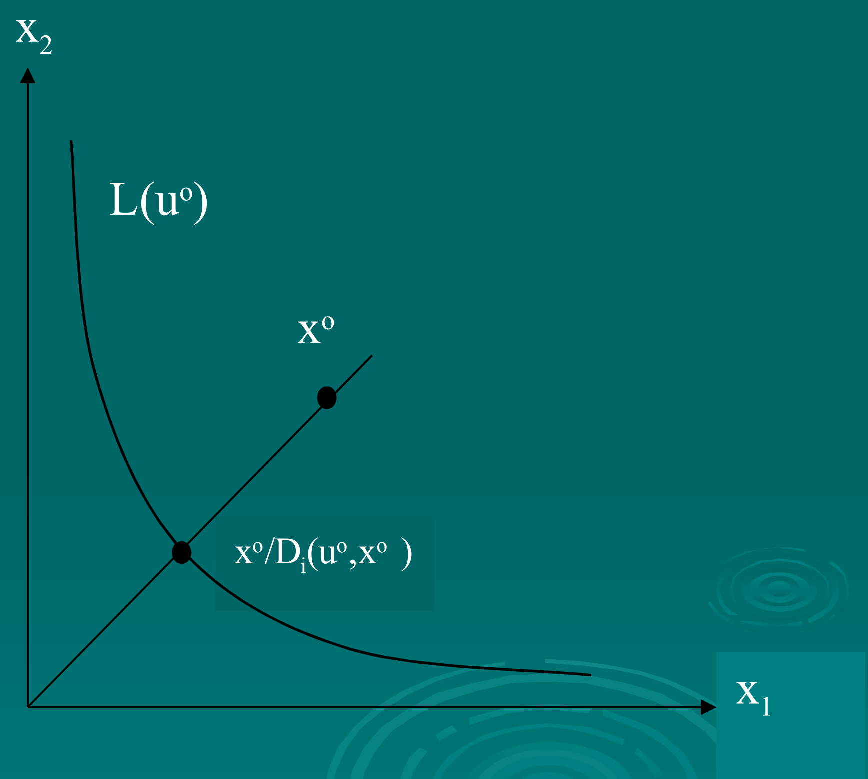
$$D(u,x,t) = \max_{\theta}\{\theta : (\frac{x}{\theta}) \in L(u,t), \theta \in R_{+}\}$$

- **Maximum amount of the input vector can be deflated, keeping the output vector in the technology set**
- **Dual to cost function according to Shephard's Lemma**
- **FOC: how many units of desirable output (swordfish) would be willing to forego to reduce one sea turtle bycatch**

$$r_i^* = r_j^* . \frac{\partial D(u,x.t)/\partial u_i}{\partial D(u,x,t)/\partial u_j}$$

- **Swordfish observed price= shadow price**

derive shadow price for sea turtle



Functional form to derive value of distance function

- Translog functional form

$$LnD(u,x,t) = \alpha_0 + \sum_{n=1}^{N} \alpha_n \ln x_n + \sum_{m=1}^{M} \beta_m \ln u_m + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{M} \alpha_{nn'} \ln x_n \ln x_{n'}$$
$$+ \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M} \beta_{mm'} \ln u_m \ln u_{m'} + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{M} \gamma_{nm} \ln x_n \ln u_m$$
$$+ \alpha_t . t + \frac{1}{2}\alpha_{tt} t^2 + \sum_{n=1}^{N} \alpha_{nt} t \ln x_n + \sum_{m=1}^{M} \beta_{mt} t \ln u_m$$

- n=1,2: trip length (days, weighted by net tons), hooks in that trip (1,000)
- m=1,2,3: swordfish catch, tuna catch, catch of other species (1,000 pounds)
- m=4: number of sea turtle

Estimation of Parameters

$$Minimize_{(\alpha,\beta,\gamma)} \sum_{k=1}^{212} \ln D(u,x,t)$$

Subject to

$$\ln D(u,x,t) \geq 0,$$ C1

C1: value of input distance function >=1

$$\frac{\partial \ln D(u,x,t)}{\partial x_n} \geq 0$$ C2

C2: non-decreasing in inputs

$$\frac{\partial \ln D(u,x,t)}{\partial u_m} \geq 0$$ C3

C3: non-increasing in desirable outputs

$$\frac{\partial \ln D(u,x,t)}{\partial u_m} \geq 0$$ C4

C4:non-decreasing in undesirable output

$$\sum_{n=1}^{2} \alpha_n = 1$$ C5a

$$\sum_{n=1}^{2} \alpha_{nn'} = 0$$ C5b

$$\sum_{n=1}^{2} \gamma_{nm} = 0$$ C5c

$$\sum_{n=1}^{2} \alpha_{nt} = 0$$ C5d

C5: linear homogeneity in inputs

$$\alpha_{nn'} = \alpha_{n'n}$$ C6a

$$\beta_{mm'} = \beta_{m'm}$$ C6b

C6: parameter symmetry conditions for translog function

Descriptive statistics of variables included in the analysis (54 vessels, 212 obs., 1991-1999)

Variable (units) |	Mean	Std. Dev.	Min	Max
Inputs				
Trip Length (days standardized by net tons)	21.63	12.95	0.41	55.74
Hooks (thousands)	12.63	5.10	0.75	25.40
Desirable Outputs				
Swordfish (thousand pounds)	20.42	12.29	0.62	66.39
Tuna (thousand pounds)	4.13	3.45	0	16.09
Other (thousand pounds)	1.18	1.40	0	9.46
Undesirable Outputs				
Turtle (number)	1.84	1.41	1	10

Fish Abundance Effects on Outputs

- Catch of different species is sensitive to harvestable stocks
- Abundance indices for the species in different periods and areas are indicators of resource conditions
- Weigh each output of every trip by abundance indices

Abundance Indices Derivation

- Seemingly Unrelated Regression (SUR); analyze catch rates with assumption of lognormal error distributions

- Explanation variables: Year, Month, Vessel classes, Regions, Trip types

$$\ln \mu_{csyqa} = \varphi + \delta_c + \phi_s + \lambda_y + \nu_q + \eta_a + \varepsilon_{csyqa}$$

μ: expected catch rate for vessel length c in month s of year y in region a by trip type q.

φ: catch rate obtained by a tuna trip of vessel 1 in January 1991 in area 1.

δ: vessel classes; ϕ: month; λ: year; ν: trip types; η: region.

Yearly Average Technical Efficiency and Shadow Prices

Landing year	Technical Efficiency	Shadow Prices (in 1991 USD)
1991	0.7658	37,243
1992	0.6734	33,515
1993	0.5672	27,082
1994	0.6329	38,172
1995	0.7271	34,244
1996	0.7378	24,232
1997	0.6065	16,901
1998	0.6550	23,023
1999	0.6948	16,496
1991-1999	0.6707	32,561

Chakravorty and Nemoto (2000): $14,000 in 1995 USD ($12,343 in 1991 dollars) per loggerhead turtle; use number (66) (Kleiber,1998)

Curtis and Hicks (2000): $41,262 per turtle from seasonal closure and $ 52, 976 per turtle; =$33,843 (seasonal) and $43,509 (full) in 1991 USD

Pradham and Leung (2004): Between $35,000-$55,000 per sea turtle

Shadow Prices by Trip Types

	Swordfish	Mixed
Landing Year	Shadow Price (in 1991 USD)	Shadow Price (in 1991 USD)
1991	39,597	20,769
1992	34,573	26,534
1993	27,830	18,610
1994	39,328	9,265
1995	34,844	31,994
1996	23,509	25,161
1997	10,084	17,874
1998	32,545	18,262
1999	14,233	17,502

Shadow prices by month

Landing Month	Shadow Prices (in 1991 USD)
1	13,363
2	23,875
3	32,836
4	41,432
5	48,961
6	34,874
7	23,631
8	22,709
9	33,795
10	8,416
11	40,373
12	26,086

Sea turtle catch and Shadow Price by areas

	Area A		Area B		Area C	
Landing Year	Shadow Price (in 1991 USD)	Number	Shadow Price (in 1991 USD)	Number	Shadow Price (in 1991 USD)	Number
1991	32,791	26	43,132	8	41,728	8
1992	35,282	26	41,838	16	21,357	15
1993	30,370	21	23,534	43	33,384	5
1994	47,753	18	33,742	26	20,762	3
1995	26,724	9	37,462	13	38,286	5
1996	25,316	16	22,082	17	31,200	2
1997	9,292	10	21,819	4	32,578	1
1998	20,487	26	16,315	25	45,438	3
1999	17,502	8	8,931	16	20,532	11

Conclusions

- $32,651 (1991 USD) per turtle, close to Curtis & Hicks (2000) and Pradham & Leung (2004) estimates, higher than Chakravorty and Nemoto (2000) estimate
- Not assuming policy implementation; modest data requirement; information for trade-offs between incidental capture and costs of bycatch abatement
- Reveal variation pattern by trip characteristics
- Shortcoming: nonstochastic

Acknowledgements

This research is funded by
The Joint Institute of Marine and Atmospheric Research of the University of Hawaii &
National Oceanic and Atmospheric Administration

Thanks to

Pelagic Fishery Research Program
Honolulu Laboratory, National Marine Fishery Services