SASI Opportunity Cost Analysis

The objectives of the SASI Opportunity Cost Analysis were to 1) understand and quantify the trade-offs inherent in the use of durable fishing gear restriction (closed) areas; and 2) define measurable thresholds for achieving the requirements to minimize adverse effects on habitat from fishing to the extent practicable, as specified in the Omnibus Amendment 2 Goals and Objectives.

INTRODUCTION

In a 2002 report entitled "*Effects of Trawling and Dredging on Seafloor Habitat*" (NRC 2002) the National Research Council outlined three primary tools available to fishery managers for minimizing the adverse effects from fishing on fish habitat as area closures, gear modifications and effort reductions. Large-scale, year-round area closures have been used by New England fishery managers for over fifteen years. Since 2004, these areas have also been used as a tool to minimize the adverse effects from fishing on habitat (NEFMC 2003a, 2003b). It is well recognized that both temporary and year-round fishing area closures result in effort displacement if they are not accompanied by commensurate catch or effort controls (Rijnsdorp et al. 2001, Dinmore et al. 2003). However, few studies have addressed the trade-off between habitat recovery in areas closed to fishing and the additional adverse effects of fishing in open areas. In the most pertinent and thorough such analysis, Hiddink et. al. (2006) looked specifically at the effects of area closure and effort control tools on the biomass, production, and species richness of benthic communities in the North Sea and concluded:

> *"If the areas closed to fishing have low levels of production because of high natural disturbance, and/or recover quickly after disturbance, then closure tends to have a negative effect, because trawling effort may redistribute to more productive habitats with longer recovery times. If the closed areas have high production in the absence of disturbance, and effort is displaced to areas where production is low, then closure is more beneficial."*

Viewed through an economist's lens, these effects are nothing more than the opportunity cost associated with area closures. Isard et al. (1968) provided the general framework for quantifying the relationship between coupled economic and ecological systems by defining interaction matrices between economic and non-economic commodities. Laurent and Hite (1972) were among the first to provide a conceptual basis for calculating the tradeoffs between economic growth and environmental quality by defining the direct and indirect linkages between economic and ecological systems. They estimated an input-output (I-O) model based on matrices of sector-level linked economic and ecological systems using a similar approach to modern economic I-O models (Minnesota IMPLAN Group, 1997). Importantly, Laurent and Hite were the first to consider the concept of an environmental income multiplier, estimating the environmental repercussions of sector-level marginal income changes.

METHODS

Jin et al. (2003) adopt the Isard approach by merging a coastal economic I-O model with a linear marine food web model that measures the direct and indirect effects on natural resources from marginal changes in final demand. To focus our analysis specifically on the relationship between fishing and adverse effects on habitat, we pull from their matrix an element e_{ij}, called the "environmental impact coefficient" which they use to estimate impacts of economic outputs on the ecosystem. The environmental impact coefficient is defined as

$$e_{ij} = \frac{f_{ij}}{x_i}, \qquad (1)$$

where f_{ij} is the amount of ecological commodity *j* affected by the output from industry sector *i*, and x_i is the output of industry sector *i*. We focus on this environmental impact coefficient as an appropriate way to estimate the relationship between the benefits from fishing (industry outputs, *x*) with their costs (industry effects on an ecological commodity, *f*). The SASI model provides spatially-specific estimates of the impact of various fishing gears on structure-forming habitat with both a susceptibility and recovery component, and therefore is uniquely well-suited to estimating *f*. Industry outputs can be considered in terms of fish production, revenue or profit. Using SASI's uniform grid, we are able to estimate *e* at the individual parcel level, and from there derive an approximation of the opportunity costs of area closure.

Adapted to the SASI framework, the basic equation is

$$e_{ip} = \left(\frac{z^{net}}{x}\right)_{ip} , \qquad (2)$$

where Z^{net}_{ip} is the net stock of quality-adjusted area swept (in km^2, as calculated in the SASI model) that has had its functional value as structure-forming habitat reduced as a result of fishing by gear type *i* at parcel *p*, and x_{ip} is the profit ($) derived as a result of fishing by gear type *i* at parcel *p*. Because *z* is a time-dependant variable, a true 'cost' estimate requires summing all of the adverse effects that result from a particular fishing event. Similar to net present value accounting, we simply sum these effects over their lifespan. A zero discount rate is assumed, as there is little basis for assuming a time-value for structure-forming habitats—a square kilometer of unaffected (or adversely affected) habitat will not become more than a square kilometer at any time in the future. This non-discounted lifecycle estimate of adverse effect, its net stock (Z^{net}), is defined as

$$z^{net}{}_{ip} = \sum_{t=1}^{n} z_{ip} \, , \qquad (3)$$

where *t* is the duration, in years, of the adverse effect for each unit of fishing activity. The length of the adverse effect lifecycle for a given fishing event is directly related to the recovery times (in years) of the structural habitat features inferred to the substrate(s) found within the parcel being fished.

Profit (*x)* is calculated as the product of all revenues *r* and variable trip-level costs *c* across gear types *i* and parcels *p* as

$$x_{ip} = (r - c)_{ip} \, . \qquad (4)$$

Note that crew remuneration is not included in *c*. Fixed costs do not vary across parcels or influence fishing decisions at the margin and are not included in our profit estimate. Profit is not discounted over the duration of the adverse effect, as the monetary benefits of fishing are instantaneous.

The environmental impact coefficient provides a quantitative method for comparing the total amount of adverse effect (Z^{net}) needed to generate a dollar of fishing profit for each gear type at each parcel. Comparisons may be made across parcels and across gear types to determine the most (and least) practicable combinations for potential management areas. Further, the opportunity costs associated with area closure may be calculated at a coarse scale by comparing the ratio of mean e_i at parcels proposed for closure relative to those open to fishing. An estimate of total opportunity cost can be generated by assuming an even redistribution of fishing effort across the remaining parcels and then comparing the resultant Z^{net} required to compensate for the profits lost under the closure scenario. A more refined version of this estimate could include a coupled bio-economic site choice model, which we do not have the means to explore at this time.

DATA

Z^{net} is parameterized using self-reported trip-level data (VTR) for actual fishing trips made by vessels fishing with any of the ten gear types used in the SASI model during the 1996-2009 timeframe. Document 2 contains a more complete discussion on the treatment of these data. Table 1 shows the mean Z^{net} and trip length by gear type and year.

The *x* variable is composed of *r*, trip-level revenue, and *c*, trip-level costs. Trip-level revenues are generated using a combination of dealer reported-landings and, when dealer-level data are not available or are incomplete, self-reported VTR data. Observer data are used to estimate two trip-level cost models, and these models are applied to the VTR point data used in the SASI model. The time frame for observer data collection is 2003-2009, whereas the time series for the SASI model is 1996-2009. This inconsistency is likely to induce bias, as trip-level costs (particularly fuel costs) may not be representative of the earlier years. VTR trips with no valid location data are deleted. Hydraulic clam dredge gear is excluded due to difficulties in computing trip-level revenue and insufficient observer data for generating a meaningful trip cost model. All values are converted to 2007 dollars using the Bureau of Labor Statistics producer price index for unprocessed and packaged fish, series WPU0223.

Trip cost, the dependant variable, includes items such as ice, food, fuel, intra-trip vessel or gear damage, miscellaneous supplies, water, oil and bait. As these components of trip cost were only reported directly for observed trips, a linear model was specified to estimate trip cost for each trip in the analysis from the data available for all trips (i.e. trip duration, crew size, vessel horsepower, and gear type). Several model specifications and combinations of explanatory variables were explored. Trip costs were sensitive to trip duration, and therefore separate cost models were estimated for trips less than 24 hours (Table 2) and for trips equal to or greater than 24 hours (Table 3). Table 4 presents the annual average trip revenues, trip costs and profits by gear type.

Table 1 – Mean Z^{net} and trip length (days) by year and gear type. Short (< 24h) and long (≥ 24 hr) trips were combined to produce these averages.

	gen otter trawl		shrimp trawl		squid trawl		raised trawl	
year	Znet	trip length	Znet	trip length	Znet	trip length	Znet	trip length
1996	-5.54	1.9	-1.34	0.55	-4.85	2.36	.	.
1997	-5	1.71	-1.41	0.6	-3.74	2.12	.	.
1998	-4.79	1.64	-1.35	0.55	-4.92	2.5	.	.
1999	-4.81	1.68	-1.3	0.57	-3.33	2.09	.	.
2000	-4.14	1.55	-1.32	0.51	-2.59	1.39	.	.
2001	-3.85	1.64	-1.16	0.5	-3.37	1.85	.	.
2002	-3.16	1.46	-1.25	0.61	-3.34	1.84	.	.
2003	-3.32	1.51	-1.09	0.47	-4.73	2.51	-1.03	0.96
2004	-3.18	1.45	-1.11	0.48	-3.84	2.07	-1.04	0.61
2005	-3.08	1.41	-1.07	0.49	-4.88	2.71	-0.78	0.56
2006	-3.13	1.43	-1.01	0.46	-4.11	2.18	-0.75	0.81
2007	-3.27	1.43	-1.12	0.5	-3.61	2.05	-0.76	0.54
2008	-3.09	1.36	-1.16	0.5	-3.79	2.02	-0.7	0.44
2009	-3.44	1.28	-1.13	0.45	-4.58	2.39	-0.87	0.46

	la scallop dr		gc scallop dr		longline		gillnet	
year	Znet	trip length	Znet	trip length	Znet	trip length	Znet	trip length
1996	-3.83	7.06	-0.1	0.44	-0.04	0.73	0	0.79
1997	-3.08	6.36	-0.12	0.45	-0.03	0.75	0	0.64
1998	-3.28	6.02	-0.13	0.46	-0.03	0.76	0	0.63
1999	-2.92	5.73	-0.13	0.46	-0.28	0.63	0	0.72
2000	-2.73	5.92	-0.17	0.53	-0.02	0.69	0	0.72
2001	-2.82	6.09	-0.18	0.55	-0.05	0.68	0	0.73
2002	-2.59	7.08	-0.18	0.54	-0.03	0.86	0	0.67
2003	-2.4	6.61	-0.16	0.56	-0.02	0.82	0	0.64
2004	-2.15	5.84	-0.15	0.59	-0.02	0.72	0	0.61
2005	-1.3	3.27	-0.16	0.61	-0.03	0.74	0	0.61
2006	-1.15	2.6	-0.19	0.67	-0.03	0.71	0	0.58
2007	-1.44	2.78	-0.18	0.67	-0.03	0.72	0	0.51
2008	-1.72	2.95	-0.17	0.64	-0.04	0.8	0	0.53
2009	-2.35	3.53	-0.16	0.59	-0.03	0.86	0	0.48

	pots and traps	
year	Znet	trip length
1996	-0.01	0.58
1997	-0.01	0.58
1998	-0.01	0.57
1999	-0.01	0.58
2000	-0.01	0.54
2001	-0.01	0.54
2002	-0.01	0.53
2003	-0.01	0.55
2004	-0.01	0.54
2005	-0.01	0.52
2006	-0.01	0.53
2007	-0.01	0.53
2008	-0.01	0.55
2009	-0.01	0.56

Table 2 – Trip cost model with natural log of trip cost as dependant variable for trips less than 24 hours, Adj R^2 = 0.525 (OLS). Gillnet and longline are categorical variables representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours.

Variable	*Parameter Estimate*	*Standard Error*	*t Value*	*Pr > |t|*
Intercept	2.90496	0.06213	46.75	<.0001
Gillnet	-0.57755	0.02764	-20.9	<.0001
Longline	0.24488	0.06531	3.75	0.0002
Crew size	0.32479	0.01631	19.92	<.0001
LN(duration)	0.86415	0.02679	32.26	<.0001

Table 3 – Trip cost model with natural log of trip cost as dependant variable for trips greater than or equal to 24 hours, Adj R^2 = 0.807 (OLS). Gillnet is a categorical variable representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours; $horsepower^2$ is the vessel horsepower squared.

Variable	*Parameter Estimate*	*Standard Error*	*t Value*	*Pr > |t|*
Intercept	1.8691	0.09207	20.3	<.0001
$Horsepower^2$	1.81E-07	3.35E-08	5.41	<.0001
Gillnet	-0.76861	0.04381	-17.54	<.0001
Crew size	0.14529	0.01171	12.41	<.0001
LN(duration)	1.2594	0.02187	57.58	<.0001

Table 4 – Average value, cost, and profit for all trips, and average trip duration (days) by year and gear type.

	gen. otter trawl				shrimp trawl				squid trawl			
year	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**
1996	7,434	1,787	5,648	1.9	2,032	357	1,675	0.55	11,696	2,199	9,497	2.36
1997	6,951	1,569	5,381	1.71	1,687	387	1,300	0.6	9,048	1,874	7,174	2.12
1998	6,559	1,479	5,080	1.64	1,598	346	1,252	0.55	12,414	2,495	9,919	2.5
1999	6,757	1,533	5,225	1.68	1,246	347	899	0.57	8,815	2,026	6,789	2.09
2000	6,667	1,395	5,272	1.55	1,664	315	1,349	0.51	6,157	1,232	4,925	1.39
2001	7,104	1,485	5,619	1.64	943	309	634	0.5	7,726	1,704	6,021	1.85
2002	6,559	1,317	5,242	1.46	1,318	404	914	0.61	8,139	1,674	6,466	1.84
2003	6,935	1,365	5,570	1.51	1,296	289	1,006	0.47	12,132	2,394	9,738	2.51
2004	7,252	1,311	5,941	1.45	1,299	290	1,009	0.48	11,742	1,923	9,819	2.07
2005	6,297	1,266	5,031	1.41	1,153	291	862	0.49	17,315	2,722	14,594	2.71
2006	6,665	1,288	5,376	1.43	1,420	283	1,137	0.46	11,469	2,115	9,354	2.18
2007	6,358	1,306	5,053	1.43	1,447	322	1,125	0.5	10,069	2,084	7,985	2.05
2008	6,639	1,231	5,408	1.36	1,302	316	986	0.5	9,474	1,966	7,507	2.02
2009	6,388	1,155	5,234	1.28	1,231	290	940	0.45	14,255	2,310	11,946	2.39

	raised footrope trawl				limited access scallop dr				general category scallop dr			
year	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**
1996	.	.	.	.	44,695	10,804	33,891	7.06	972	294	678	0.44
1997	.	.	.	.	38,452	9,399	29,053	6.36	1,074	281	793	0.45
1998	.	.	.	.	29,936	8,666	21,270	6.02	976	288	688	0.46
1999	.	.	.	.	47,359	8,265	39,095	5.73	1,231	294	936	0.46
2000	.	.	.	.	57,423	8,725	48,698	5.92	1,643	454	1,189	0.53
2001	.	.	.	.	56,322	8,989	47,333	6.09	1,712	438	1,274	0.55
2002	.	.	.	.	62,417	10,546	51,872	7.08	1,753	392	1,361	0.54
2003	3,139	791	2,349	0.96	61,867	9,617	52,250	6.61	1,884	390	1,494	0.56
2004	2,253	383	1,870	0.61	67,458	8,153	59,305	5.84	2,337	441	1,897	0.59
2005	2,112	454	1,658	0.56	42,911	4,129	38,782	3.27	3,008	479	2,529	0.61
2006	2,932	661	2,270	0.81	24,753	3,043	21,710	2.6	2,343	493	1,850	0.67
2007	2,123	381	1,742	0.54	26,566	3,338	23,228	2.78	2,343	497	1,846	0.67
2008	1,979	343	1,636	0.44	32,499	3,729	28,770	2.95	2,444	471	1,973	0.64
2009	2,072	358	1,714	0.46	41,260	4,695	36,565	3.53	2,636	458	2,178	0.59

	longline				gillnet				pots and traps			
year	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**	**trip_value**	**trip_cost**	***profit***	**trip_duration**
1996	2,725	592	2,133	0.73	2,792	320	2,473	0.79	2,342	432	1,911	0.58
1997	2,641	640	2,001	0.75	2,609	263	2,346	0.64	2,086	418	1,668	0.58
1998	2,711	645	2,065	0.76	2,670	253	2,417	0.63	1,865	409	1,456	0.57
1999	2,737	463	2,274	0.63	3,293	282	3,010	0.72	2,232	416	1,816	0.58
2000	2,452	517	1,935	0.69	3,068	265	2,803	0.72	2,189	372	1,817	0.54
2001	2,719	484	2,235	0.68	2,937	265	2,672	0.73	1,948	376	1,572	0.54
2002	3,057	625	2,432	0.86	3,015	244	2,771	0.67	2,008	372	1,636	0.53
2003	2,885	621	2,265	0.82	2,813	239	2,575	0.64	2,112	390	1,722	0.55
2004	4,061	584	3,477	0.72	2,558	228	2,331	0.61	1,982	381	1,601	0.54
2005	3,884	564	3,320	0.74	2,791	221	2,570	0.61	2,086	371	1,715	0.52
2006	2,985	546	2,440	0.71	2,545	216	2,328	0.58	1,971	362	1,608	0.53
2007	3,057	627	2,430	0.72	2,408	196	2,213	0.51	1,813	366	1,447	0.53
2008	2,787	654	2,133	0.8	2,343	201	2,142	0.53	1,834	381	1,453	0.55
2009	3,006	684	2,322	0.86	1,963	185	1,779	0.48	1,812	395	1,417	0.56

RESULTS

The environmental impact coefficient, *e,* is calculated as the mean *e* across all years at the parcel level (i.e. 100 km^2 grid cell) for all gear types. The estimate includes only parcels with three or greater trips per year and three or greater years of data. Parcel-level inter-annual variability is reported. The *e* coefficient may accurately be interpreted as the quality-adjusted area swept, in square kilometers, that results from the generation of $1,000 of gross profit at the individual trip level. While this summary table does not explore the spatial distribution of *e*, the rank order and magnitude of the adverse effect generated per dollar provide a useful approach to understanding the impacts of various fishing gears on structural habitat.

Table 5 – Unweighted mean *e* across all included grid cells and years, by gear type

Gear	*# grid cells*	*mean e*	*stddev e*
Generic otter trawl	1271	5.00	8.30
Shrimp trawl	96	8.10	11.73
Squid trawl	195	2.82	3.69
Raised footrope trawl	5	1.48	1.71
Limited Access scallop dredge	446	0.64	1.05
General Category scallop dredge	215	0.68	1.09
Demersal longline	110	0.11	0.26
Sink gillnet	688	0.03	0.08
Trap gear	601	0.04	0.07

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