Ex-Vessel Value of Fishery Production Foregone in Mt. Hope Bay as a Result of Operations at USGEN of New England's Brayton Point Station.

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Introduction-

Power generation at Brayton Point Station (BPS) on Mt. Hope Bay has been implicated in the collapse of winter flounder in Mt. Hope Bay (Gibson 1993, 1996, 2002). The most recent study showed that winter flounder in Mt. Hope Bay declined in abundance more so than in other areas and that the decline began as early as 1972. That study strongly implicated the utility as the cause for the decline since multiple control series were used to exclude other factors influencing abundance. The Gibson (1996) study showed that the entire fish community sampled by otter trawl in the vicinity of the plant showed anomalous abundance patterns when compared to other areas. Essentially, the fish community collapsed abruptly in 1985-1986 after modifications were made to unit 4 at BPS. The Gibson (2002) report showed that impacts were occurring prior to 1985. The fish community was already stressed when unit 4 began operation in open cycle cooling mode. Regulators and government agencies contemplating remedies for impacts need to consider the value of fisheries resources missing as a result of operations at BPS. Fish may be directly killed at power plants through impingement and entrainment at cooling water intakes. Habitat may be degraded through waste heat discharge resulting in lost fishery production.

Assessing the value of lost fishery resources requires an estimate of the missing biomass. The usual convention is to model production foregone (Rago 1984, Jensen et al. 1988). Production by a fish population is the sum total of biomass elaborated during a time period regardless of the fate of that biomass (Chapman 1978). It includes biomass lost to all mortality agents during the period. It is distinguished from fishery landings in that it includes biomass accrued by survivors and that lost due to natural mortality events. Production foregone is the production that would have been realized by fish killed by environmental disturbances such as power generation, had they completed a lifespan (Rago 1984). Goodyear (1988) showed that power plant mortality competed directly with fishing mortality so that the presence of the former limited the amount of fishing pressure that could be exerted. While denied fishing opportunities are the most obvious loss, denied ecological services also need to be considered. Since most natural deaths in the marine environment are caused by predation, power plant losses remove food resources from the benthic and pelagic wood webs. Computation of production-foregone accounts for both denied catch opportunities and biomass contributing to higher trophic levels. Attaching monetary value to the production foregone is more difficult. The simplest approach is to assign a value to the production commensurate with the ex-vessel value in a commercial fishery.

Methods and Data Sources-

<u>Biomass Dynamic Assessment Models</u>- Rago (1984) calculated production foregone directly from numbers at age killed assuming exponential growth and mortality over the potential life span. Jensen et al. (1988) estimated foregone production indirectly using a yield per recruit analysis with and without mortality terms for impingement and entrainment. The production differential on a per recruit basis represented production foregone per recruit. Combining this approach with the Rago method allowed estimation of the total recruitment in the indirect method that led to consistent estimates of total production foregone. In other words, the per recruit indirect method was scaled to match the direct estimate which was based on an absolute body count. The utility of the Jensen's approach was that production foregone could be placed in the context of total population production. The method however relied on the equilibrium assumption that vital rates of growth, mortality, and recruitment are constant so that the production of the population in any one year is equal to the production of an incoming recruitment over it's lifespan. Equilibrium conditions rarely exist and vital rates are subject to variations from environmental factors and may be density dependent as well. Further, other impacts from power generation such as habitat degradation from waste heat are not considered. Ironically, Jensen et al. (1982) had the solution to the scaling and nonequilibrium problems in their surplus production or biomass dynamic model (BDM) that included terms for entrainment and impingement in addition to the usual fishing mortality rate.

BDMs are routinely used to assess fish stocks because data requirements are modest and they provide direct estimates of management targets such as maximum sustainable yield (MSY). They are a mass balance approach in which stock biomass in a new year is the sum of last years biomass plus new production minus the catch removed (Hilborn and Walters 1992). New production is the net balance between additions from growth and recruitment and natural losses. If stock growth is assumed to follow the familiar logistic curve, a simple biomass model in discrete form is:

$$B_t = B_{t-1} + rB_{t-1}(1-(B_{t-1}/k)) - C_{t-1} + e_p \qquad (1)$$

where:

B = population biomass
C = catch
r = per capita rate of increase
k = unfished population biomass.
t = year
e_p = process error term.

The r parameter is a measure of population growth rate in the absence of density dependent factors, that is at low abundance. The term in parenthesis in eq. 1 is the density dependent feedback mechanism that reduces stock growth when abundance is high. The discrete form of the production model is a simplification over the differential equation that forms the basis for example of Prager's (1994) ASPIC application. Hilborn and Walters (1992) note that the discrete and differential forms are essentially equivalent unless extreme values of r and fishing mortality (F) occur.

Since the actual biomass levels are not known, an observation model is needed in the form of survey catch per unit effort:

$$B_t = (U_t)/q + e_m \qquad (2)$$

where:
- *B= biomass*
- *U= survey abundance*
- *q= catchability coefficient*
- *t= year*
- *e_m= measurement error term.*

The q parameter is a scaler which relates survey abundance to absolute stock abundance. Substitution of eq.2 into eq.1 and combining error terms gives the final biomass dynamic model form:

$$U_t = U_{t-1} + rU_{t-1}(1 - U_{t-1}/kq) - qC_{t-1} + e \qquad (3)$$

Parameters in eq. 3 (r,k,q) are estimated by minimizing the sum of squares deviations between observed and predicted log catch per unit effort or:

$$\text{minimize} \; \Gamma_{t=1}^{n} (\ln U_t - \ln \hat{U}_t)^2 \qquad (4)$$

A mixed error model is assumed so that the residual sum of squares (RSSQ) is composed of process error in the population dynamics model and measurement error in the CPUE indices (Polachek et al. 1993). This procedure involves estimation of additional parameters in the form of process errors and a starting biomass level (U_0). Weighting in the minimization was adjusted until process error accounted for 10-20% of the RSSQ (Conser and Idoine 1992). This allows for some deviation from the logistic population model but allocates most of the error to the input indices. Solutions can be found using the EXCEL problem solver employing a quasi-Newton search method. This model was adapted from an EXCEL production model application provided by J. Collie from the University of Rhode Island Graduate School of Oceanography. As suggested by Hilborn and Walters (1992) and Prager (1994), the objective function (eq. 4) can be expanded to consider auxiliary data.

$$\text{minimize} \mathop{\Gamma}_{t=1}^{n} (lnU_t - ln\hat{U}_t)^2 + \forall_1 \mathop{\Gamma}_{t=1}^{n} (lnF_t - ln\hat{F}_t)^2 + \forall_2 \mathop{\Gamma}_{t=1}^{n} (lnC_t - ln\hat{C}_t)^2 \quad (5)$$

Historical estimates of F from tagging studies or recreational CPUE (C) can be used to aid in estimation of model parameters. Auxiliary data can be given various weights depending on the level of confidence in the data.

BDM based assessments for the RI area were available for a number of species including winter flounder, windowpane flounder, tautog, lobster and quahaugs. For this study, assessment results for winter flounder, windowpane, and tautog were obtained from Gibson (2000a, 2000b and unpublished assessments). These species are locally produced, are important in fisheries, and have declined dramatically in Mt. Hope Bay. The results include estimates of stock biomass and exploitation rates for these species in the Rhode Island area. Because the assessments use the Rhode Island Division of Fish and Wildlife (RIDFW) random-stratified trawl survey as the fishery independent abundance index in eq. 2, they include Mt. Hope Bay as a sub area. The assessment results therefore are influenced by any losses and habitat degradation occurring at BPS.

Relative Abundance Data in Mt. Hope Bay- For data on the relative abundance of fish specific to Mt. Hope Bay, I used the long term Marine Research Inc. (MRI) standard trawl survey results as reported in USGEN/MRI annual reports (USGEN/MRI 1999). The standard trawl survey began in 1972 and has continued to present day. For purposes of establishing the pre-impact biomass contribution of Mt. Hope Bay, I assumed that fishery production was proportional to surface area. Since Mt. Hope Bay is about 10% of the surface area of Narragansett Bay (Chinman and Nixon 1985), I assumed that fishery production in Mt. Hope Bay prior to the main impact was about 10% of the entire Bay. As noted in Gibson (2002), BPS came on line in the 1960’s and reached peak power output in the late 1980’s and early 1990’s. A collapse of the fishery production system in Mt. Hope Bay in association with unit 4 operation in open cycle mode was documented by Gibson (1996).

Statistical Procedures- the overall BDM model results were intercalibrated with the MRI standard trawl survey results assuming that from 1972-1985, the Mt. Hope Bay contribution was 10% of that estimated by the BDM. This is a reasonable working assumption. Although the standard trawl index did not collapse abruptly until 1985-1986, Gibson (2002) showed that it was in decline relative to other areas from 1972-1985. This indicates plant impacts prior to 1986. There is a need however to preserve sufficient degrees of freedom to do the intercalibration, so 1986 was chosen as the start point of fishery production foregone computations. A catchability coefficient for the standard trawl was estimated as:

$$q_j = \bar{I}_j / 0.1\bar{B}_j \qquad (6)$$

where: q= *catchability coefficient*
I= *mean survey index for 1972-1985*
B= *mean 1972-1985 absolute biomass level from BDM*
j= *species.*

Absolute biomass attributable to Mt. Hope Bay alone can then be estimated for each year since 1986 by dividing the annual standard trawl indices by the estimated catchability coefficient. Biomass attributable to production areas other than Mt. Hope Bay can also be obtained by subtraction i.e. total BDM estimate minus that estimated for Mt. Hope Bay alone.

The above procedures allow for a calculation of the actual biomass contribution from Mt. Hope Bay under historical and present conditions of BPS operation. The next step is to estimate the theoretical biomass that would have been present without BPS impact. The fitted BDM assessment models (eq.1) can be used to project Mt. Hope Bay biomass ahead from the main impact point (1985). This is done by adjusting eq. 1 so that catch is restricted to a Mt. Hope Bay contribution and with the logistic model carrying capacity parameter reduced to 10% of the original estimate. I also increase the estimate of r by 10% to account for the additional productivity of an unimpaired Mt. Hope Bay:

$$B_t = B_{t-1} + 1.1rB_{t-1}(1-(B_{t-1}/0.1k)) - u_{t-1} B_{t-1} \qquad (7)$$

where: B= *population biomass*
u= *baywide exploitation rate*
r= *per capita rate of increase*
k= *unfished population biomass.*
t= *year.*

Note that in eq.1, it is assumed that fishing mortality rate is uniformly distributed so that Mt. Hope Bay origin fish are exposed to the same fishing mortality rate as the baywide population. The second term on the right side of eq.1 is production (P) by the population during the time step between biomass assessments. Eq.1 can be rearranged so that production during a time step is the sum of the change in biomass and the catch that was removed:

$$P = B_t - B_{t-1} + u_{t-1} B_{t-1}. \qquad (8)$$

Finally, actual and theoretical production trends can be compared to determine production foregone as the difference.

The above procedure was followed independently for the three species for which there were BDM based assessments and for which a reasonable assumption of a local stock could be made (winter flounder, tautog, windowpane). Gibson (1996) however, showed that the entire aggregate population in Mt. Hope Bay declined dramatically in 1985-1986 including species which were not exploited by fisheries. Failure to consider these resources would underestimate the value of foregone production. To account for migratory species and unexploited local species that can not be reliably assessed via BDM, I scaled the estimate of production foregone for winter flounder, tautog, and windowpane to total fishery production foregone based on the ratio of the sum of those species to total catch in the MRI standard trawl. Since 1986, the three above species have on average accounted for 38% of the MRI standard trawl catch. Total production foregone was estimated as the sum of the above species divided by 0.38.

<u>Monetary Assessment</u>- Production foregone in biomass units was converted to dollar value using average ex-vessel price per pound data from the NMFS landings database for years 1998-2000. I applied species-specific price data to the winter flounder, tautog, and windowpane production foregone estimates. For the remaining trawl complex estimated via the scaling exercise, I used the average price of scup, butterfish, and weakfish. These species rank in the top 10 in the MRI standard trawl survey and are commercially important in RI. This approach assigns a commercial value to some additional species that are ecologically important but not exploited by fisheries. Ex-vessel price data alone ignores the significant multiplier effect that commercial landings generate as the move through the processing and retail sector of the economy. It also ignores the value of recreational fishing.

Results and Discussion-

Summary results from RIDFW BDM assessments for winter flounder, tautog, and windowpane flounder are found in Table 1. Trawl survey indices from the MRI standard trawl in Mt. Hope Bay are also included. Biomass of the three species in the RI area has fluctuated considerably over time (Figure 1). Both winter flounder and tautog declined in response to overfishing in the 1980's. Intensive management efforts in RI and on a coast wide basis have allowed for modest recoveries. Windowpane flounder also declined in the 1980's but has shown no evidence of recovery. The species is unregulated in state waters and receives only limited federal protection. Abundance of these species in Mt. Hope Bay as indexed by the MRI standard trawl is plotted in Figure 2. All three species collapse to low levels in the mid-1980's and show no signs of recovery in 1999-2001. Absolute biomass estimates for winter flounder, tautog, and windowpane from Mt. Hope Bay are found in Figure 3. They mirror the standard trawl index since the estimates are made by raising the survey values to absolute scale using the catchability coefficient. Biomass of these species in 1999-2001 is an order of magnitude below what it averaged from 1972-1985. The biomass of the three species produced outside of Mt. Hope Bay is plotted in Figure 4. Biomass of winter flounder and tautog are rebuilding and approaching levels seen in earlier years. Biomass of windowpane flounder remains low, probably due to the lack of dedicated management.

Estimated production deficits for these species in Mt. Hope Bay indicate substantial differences between realized production and that predicted in the absence of BPS operation (Figure 5). The winter flounder deficit has ranged from 70 to 140 tons per year. Tautog production deficits were very high in the 1980’s (60-145 tons) but have more recently declined to 20-40 tons. Windowpane production deficits generally track winter flounder but at a lower overall level (10-40 tons). The value of foregone fishery production, including unexploited and seasonal species, has fluctuated between 0.5 and 1.4 million dollars per year (Figure 6). Since 1986, the cumulative loss has been 12.7 million dollars. The loss is understated as recreational value is not considered, a commercial multiplier is not employed, and foregone production from plant startup through 1985 is not included.

The loss of Mt. Hope Bay as a functioning fishery production unit has imposed considerable losses on the Rhode Island commercial and recreational fishery. The impacts are well known to industry and recreational fishermen who avoid the area. Indeed, impetus for early RIDFW studies came from complaints made by commercial fishermen familiar with Mt. Hope Bay and it’s fishery history. Permitting efforts for the station should identify conservative heat and flow limits likely to facilitate recovery of the marine resources in Mt. Hope Bay.

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Table 1- Estimates of Stock Biomass and Exploitation Rate for Winter Flounder, Tautog, and Windowpane Flounder in the RI Area from Biomass Dynamic Assessment Models. Trawl Survey Indices for These Species from the MRI Standard Trawl in Mt. Hope Bay are Also Included.

	Biomass			Exploitation			MRI STD Trawl		
Year	WFL mt	TTOG mt	WND mt	WFL	TTOG	WND	WFL	TTOG	WND
59	2418.1	5106.9	887.3	0.39	0.01				
60	2486.0	5072.5	626.4	0.41	0.01				
61	2605.5	5839.8	1268.0	0.32	0.01				
62	2829.3	4823.2	712.8	0.29	0.01				
63	3093.9	5160.9	439.9	0.41	0.01				
64	3402.0	4927.5	727.4	0.60	0.01				
65	3368.6	5665.3	895.4	0.40	0.01				
66	4158.3	4677.1	1452.5	0.50	0.01				
67	4362.2	4415.7	1491.7	0.38	0.01				
68	4171.5	3437.6	1498.6	0.38	0.01				
69	4389.4	3000.2	1401.3	0.27	0.02				
70	3368.8	3638.9	1328.1	0.30	0.02				
71	2587.9	4400.0	1192.2	0.29	0.01				
72	2354.7	5243.4	1071.7	0.20	0.01	0.22	43.65	0.86	7.12
73	2651.8	4672.4	1043.4	0.22	0.01	0.22	60.37	0.78	7.14
74	2265.0	4353.3	835.6	0.19	0.02	0.12	36.24	0.84	6.92
75	1850.6	4764.5	892.5	0.21	0.03	0.33	18.89	1.04	4.37
76	2062.3	4491.2	909.6	0.20	0.08	0.27	10.60	0.99	1.55
77	2612.7	4833.2	1308.7	0.20	0.04	0.19	16.46	1.04	1.85
78	3712.2	5100.9	2018.8	0.28	0.12	0.15	48.56	1.40	9.36
79	4283.5	4411.0	2996.7	0.24	0.13	0.10	78.02	0.96	11.09
80	5460.5	3933.6	2640.2	0.25	0.27	0.09	15.75	0.60	3.72
81	5115.3	1769.0	2406.0	0.27	0.19	0.19	19.35	0.93	3.29
82	3854.0	1274.7	1604.4	0.48	0.31	0.22	49.97	1.20	6.15
83	4169.6	1721.5	1339.1	0.42	0.20	0.18	43.01	0.72	3.43
84	4079.8	2827.7	1044.8	0.42	0.35	0.27	17.93	0.62	1.83
85	3696.8	1894.5	1063.6	0.55	0.16	0.42	14.97	0.89	2.04
86	3126.7	3043.1	1231.4	0.70	0.36	0.34	5.82	0.07	0.73
87	2051.8	2007.8	1294.8	0.50	0.21	0.25	2.09	0.06	0.37
88	1750.4	1718.4	950.4	0.51	0.25	0.47	0.73	0.07	0.39
89	1418.4	1209.1	678.1	0.62	0.19	0.70	0.37	0.06	0.10
90	1216.2	874.3	442.4	0.54	0.31	0.55	0.97	0.06	0.23
91	1302.0	1128.6	313.6	0.69	0.56	0.52	0.57	0.03	0.07
92	703.4	691.4	238.5	0.65	0.67	0.60	0.49	0.06	0.07
93	556.9	594.1	190.4	0.58	0.45	0.53	0.99	0.19	0.25
94	854.1	400.6	174.7	0.53	0.52	0.26	0.44	0.02	0.25
95	1378.2	402.8	279.1	0.32	0.38	0.10	0.91	0.02	0.27
96	1535.4	494.8	517.5	0.27	0.29	0.03	0.61	0.13	0.91
97	1699.9	424.7	378.7	0.30	0.37	0.06	0.90	0.00	0.73
98	1915.1	523.2	240.6	0.30	0.31	0.06	0.53	0.11	0.40
99	1878.5	677.3	200.6	0.28	0.17	0.09	0.26	0.11	0.34
2000	1984.3	961.3	177.6	0.32	0.12	0.21	0.11	0.06	0.21
2001	1738.0	1468.3	183.7	0.30	0.15	0.15	0.21	0.20	0.05

Table 2- Logistic Model Parameters from Biomass Dynamic Models and Adjusted Values Applied to Mt. Hope Bay Projection of Biomass in Absence of Power Plant Impact

	r	k	r'	k'
Winter Flounder	0.550	9864.3	0.611	1085.1
Tautog	0.446	4479.0	0.496	492.7
Windowpane	0.450	2694.5	0.500	296.4

Table 3- Landings and Ex-vessel Price Data for Selected Species from The NMFS Weigh out Database, 1998-2000.

	Winter Flounder		
Year	Pounds	Dollars	$ per lb
1998	1236942	$1,536,438.00	$1.24
1999	1157440	$1,374,505.00	$1.19
2000	1792498	$1,756,369.00	$0.98
Mean			$1.14

	Tautog		
Year	Pounds	Dollars	$ per lb
1998	20327	$21,796.00	$1.07
1999	26107	$28,338.00	$1.09
2000	43719	$50,380.00	$1.15
Mean			$1.10

	Windowpane		
Year	Pounds	Dollars	$ per lb
1998	32225	$10,948.00	$0.34
1999	39872	$11,508.00	$0.29
2000	83272	$24,258.00	$0.29
Mean			$0.31

	Butterfish		
Year	Pounds	Dollars	$ per lb
1998	2631067	$1,457,574.00	$0.55
1999	2769577	$1,592,422.00	$0.57
2000	1288485	$494,093.00	$0.38
Mean			$0.50

		Weakfish	
Year	Pounds	Dollars	$ per lb
1998	77095	$49,885.00	$0.65
1999	126793	$87,614.00	$0.69
2000	189362	$203,004.00	$1.07
			$0.80

		Scup	
Year	Pounds	Dollars	$ per lb
1998	794769	$1,156,439.00	$1.46
1999	1280503	$1,671,840.00	$1.31
2000	1016959	$1,251,774.00	$1.23
			$1.33

Fig.1- Biomass Dynamic Model Estimates of Winter Flounder, Tautog, and Windowpane Biomass in the RI Area, 1959-2001

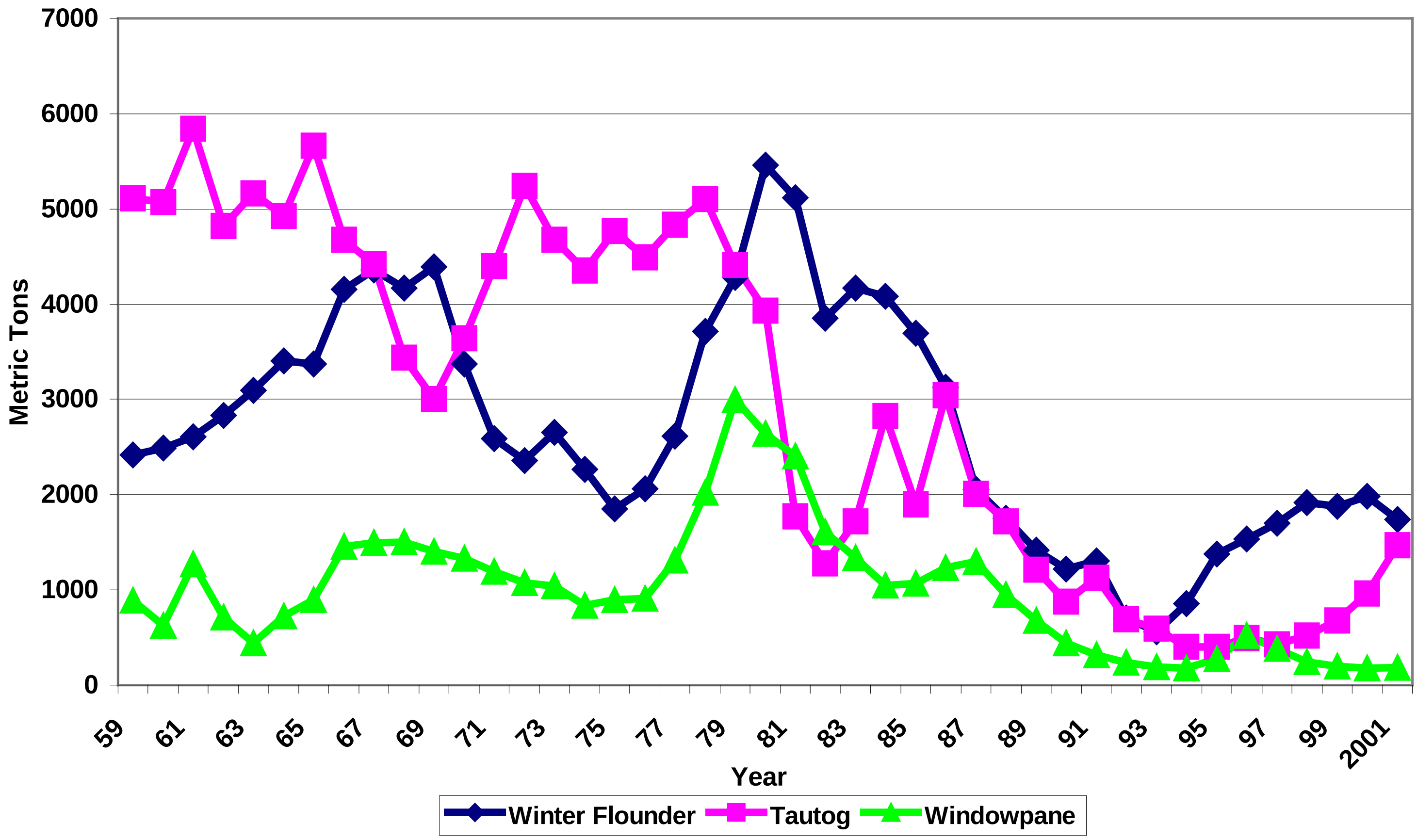


Fig.2- Abundance of Winter Flounder, Tautog, and Windowpane in the MRI Standard Trawl Survey in Mt. Hope Bay, 1972-2001

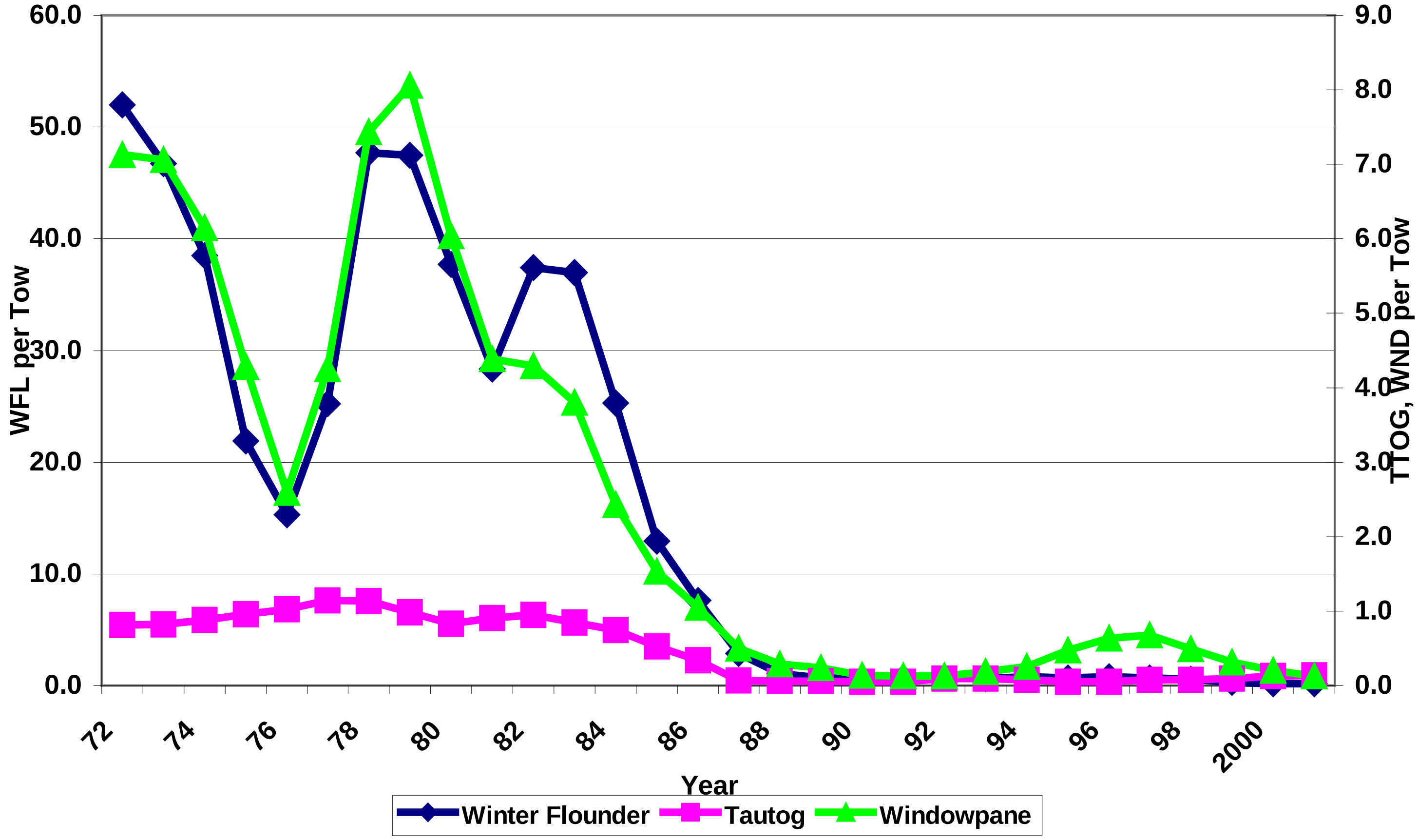
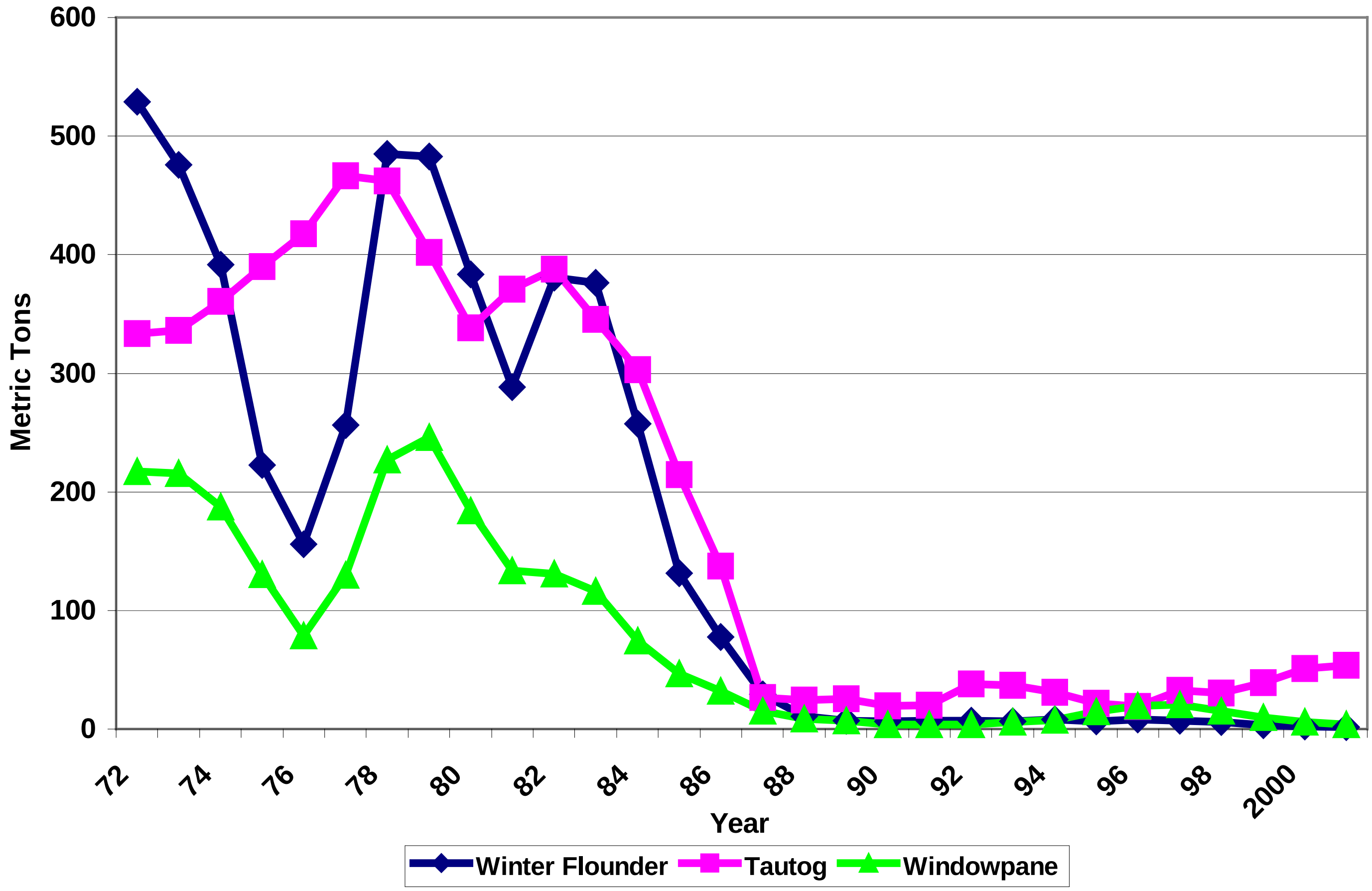


Fig.3- Estimated Biomass of RI Winter Flounder, Tautog, and Windowpane Produced by Mt. Hope Bay, 1972-2001



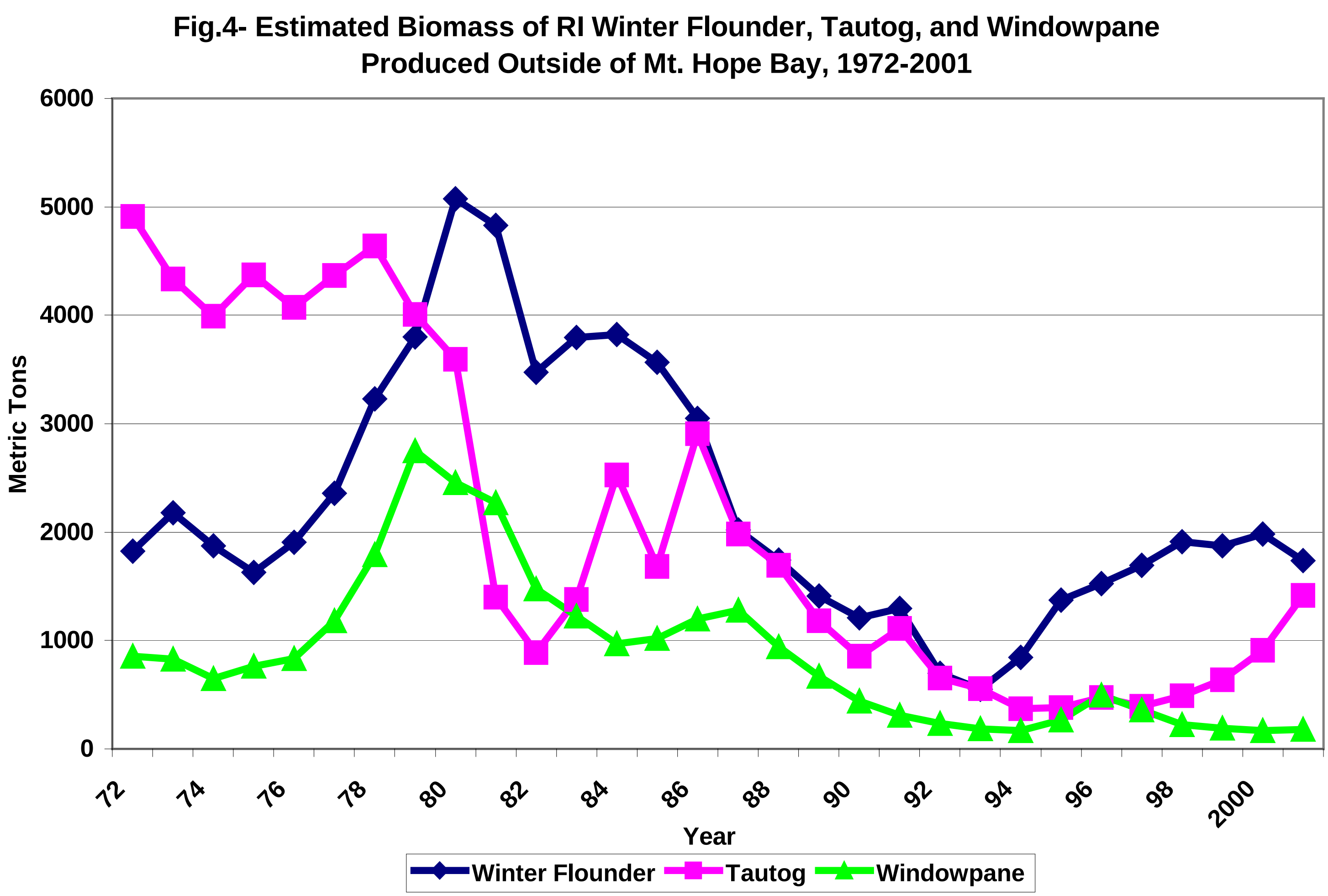


Fig.4- Estimated Biomass of RI Winter Flounder, Tautog, and Windowpane
Produced Outside of Mt. Hope Bay, 1972-2001
Metric Tons
6000
5000
4000
3000
2000
1000
0
72
74
76
78
80
82
84
86
88
90
92
94
96
98
2000
Year
Winter Flounder
Tautog
Windowpane

Fig.5- Estimated Production Deficits for Winter Flounder, Tautog, and Windowpane Produced by Mt. Hope Bay

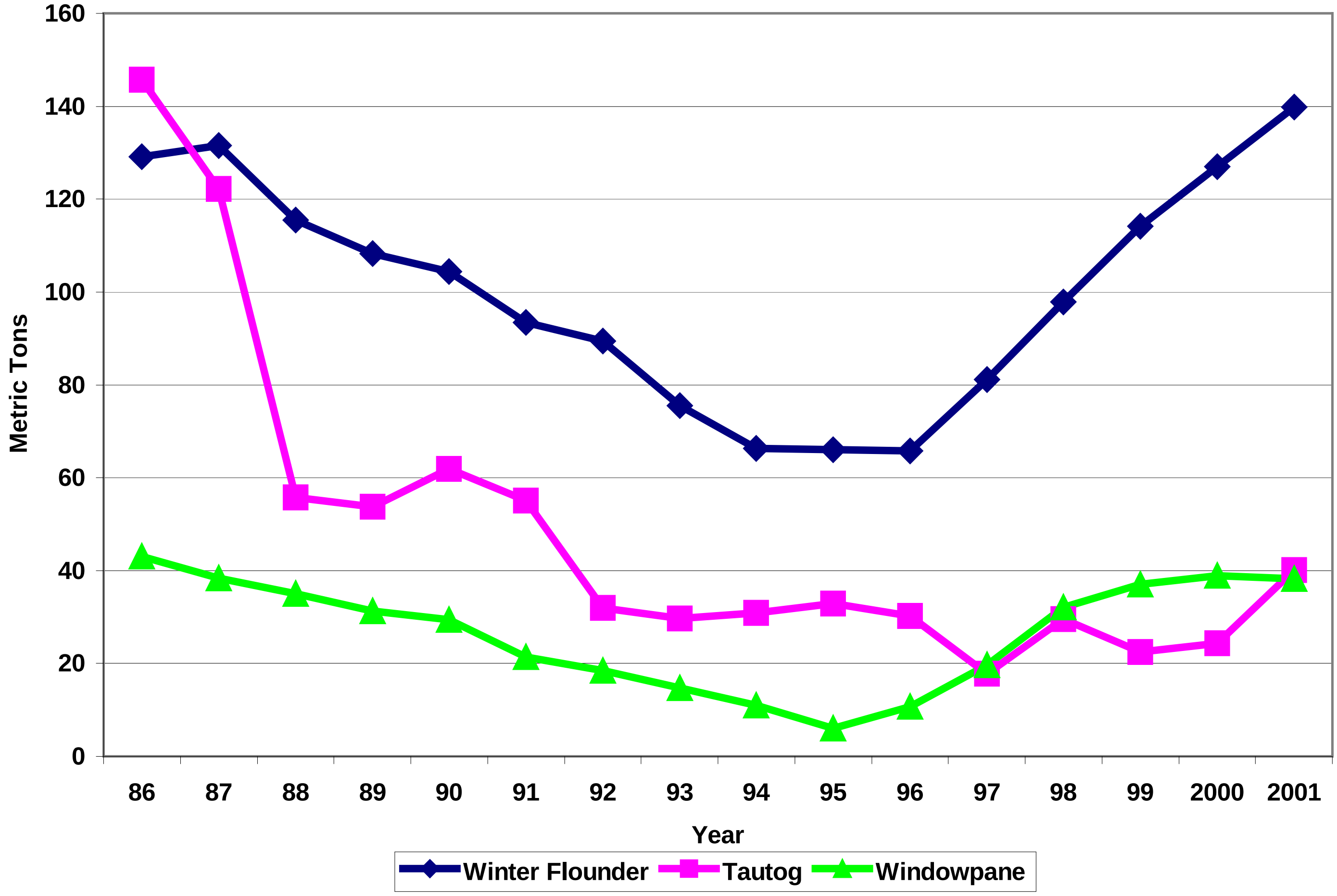


Fig.6- Value of Missing Production Based on NMFS Ex-Vessel Price Data