A Multispecies Bioeconomic Model with Biological and Harvesting Interactions using a Surplus Production Model of Stock Dynamics

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INTRODUCTION

Single species management of multispecies fisheries ignores biological interactions in addition to important technological interactions resulting from the multiproduct nature of firms' production often to the detriment of the health of the ecosystem, the stocks of fish species, and fishery profits. Despite these interactions, the predominant biological reference point for U.S. fisheries management remains a variant of the single species maximum sustainable yield (MSY). This study uses a simple single species and multispecies models to simulate the populations of each species in the future and argues for development of integrated multispecies ecological as well as multispecies economic models.

This study uses the pollock, Pacific cod, and arrowtooth flounder populations in the Bering Sea/Aleutian Islands region of Alaska as a case study. The biological interactions between these three species are such that arrowtooth flounder and Pacific cod prey on pollock, and cod and arrowtooth compete with one another for food and other resources. Similarly, a majority of vessels which target pollock over the course of a year also target cod during the same year with arrowtooth being caught as bycatch in both of these fisheries. This three species system is an ideal candidate to explore the differences between single and multispecies management models.

METHODS

The multispecies stock dynamics equations of each species are set up as a logistic escapement model, such that:

$$(1)\quad x_{i,y+1} = (1+r_i)(x_{i,y}-h_{i,y}) - \frac{r_i}{k_i}(x_{i,y}-h_{i,y})^2 + \sum_{j\neq i}^{n-1}\alpha_{i,j}(x_{i,y}-h_{i,y})(x_{j,y}-h_{j,y})\ \forall i = 1,\ldots,n,$$

where $x_{i,y}$ is the stock of species i in year y, $h_{i,y}$ is the harvest of species i in year y, r_i is the intrinsic growth rate, k_i is the carrying capacity, and $\alpha_{i,j}$ are the growth interaction parameters. After using the Prais-Winsten transformation to correct for autocorrelation, the intrinsic growth rate, carrying capacity, and interaction parameters of each species are estimated using seemingly unrelated regression for all three species, and presented in Table 1. For the single species model, $\alpha_{i,j}=0\forall i, j$, and the growth parameters are estimated again using seemingly unrelated regression.

Stock Dynamics Models		$1+r_{arth}$	r_{arth}/k_{arth}	$1+r_{cod}$	r_{cod}/k_{cod}	$1+r_{plck}$	r_{plck}/k_{plck}	$\alpha_{arth,cod}$	$\alpha_{arth,plck}$	$\alpha_{cod,plck}$
Multispecies Stock Dynamics	Arrowtooth	1.041***	-4.10E-08*					4.85E-08***	-1.28E-09	
	Pacific Cod			1.773***	-2.87E-07***			-4.28E-07***		4.25E-09
	Pollock					1.893***	-5.95E-08***		-3.77E-07	1.82E-08
Single Species Stock Dynamics	Arrowtooth	1.141***	-1.10E-07***							
	Pacific Cod			1.416***	-1.77E-07***					
	Pollock					1.687***	-5.54E-08***			

Table 1. Seemingly unrelated regression results for the single and multispecies stock dynamics equations. * denotes statistically significant at the 10% level. ** denotes statistically significant at the 5% level. *** denotes statistically significant at the 1% level.

The fleet was divided into three classes (c), small catcher vessels, big catcher vessels, and catcher processors. Total catch ($Y_{i,y}$) is determined to be a function of effort ($E^c_{i,y}$), the catchability coefficient for that species (q^c_i) and the stock of the species ($x_{i,y}$) plus the bycatch coefficient ($\gamma^c_{i,j}$) times the effort for other species j times the stock of species i summed over all vessel classes (c), such that:

$$(2)\quad Y_{i,y} = \sum_{c=1}^{3}\left(q^c_i E^c_{i,y} x_{i,y} + \sum_{j\neq i}^{n-1}\gamma^c_{i,j} E^c_{j,y} x_{i,y}\right)$$

As effort is endogenously determined, effort is instrumented for with lagged prices of thirteen potential target species (p), lagged effort, catch per unit effort ($cpue_{y-1}$), and population of the Pacific cod, pollock, and arrowtooth flounder, such that:

$$(3)\quad E^c_{i,y+1} = E^c_{i,y} + f(p_{y-1}, cpue_{y-1}, x_{y-1}) \quad \forall c = 1,\ldots,C;\ i = 1,\ldots,n,$$

After dividing both sides of equation (2) by $x_{i,y}$ and appending an error term to equations (2) and (3), the system of equations are estimated using iterated three stage least squares, and presented in Table 2. In the single species model, the bycatch coefficients ($\gamma^c_{i,j}$) all equal zero. The stock, effort, and catch will be simulated without uncertainty 100 years into the future using 2008 as a base year and constant real prices.

Fishery Production Models		Arrowtooth Effort	Cod Effort	Pollock Effort
Multispecies Small Catcher Vessel Production	Arrowtooth		1.08E-07***	3.86E-08**
	Pacific Cod		7.28E-06***	2.33E-06***
	Pollock		-2.20E-08	6.09E-06***
Multispecies Big Catcher Vessel Production	Arrowtooth		5.03E-08***	9.82E-08***
	Pacific Cod		9.44E-06***	6.43E-07***
	Pollock		-3.45E-06***	.0000123***
Multispecies Catcher Processor Production	Arrowtooth	.0000283***	1.20E-07**	2.88E-07**
	Pacific Cod	.0000206***	.0000103***	1.48E-06***
	Pollock	-.000021***	-1.26E-07	.0000365***
Single Species Small Catcher Vessel Production	Arrowtooth			
	Pacific Cod		7.76E-06***	
	Pollock			6.00E-06***
Single Species Big Catcher Vessel Production	Arrowtooth			
	Pacific Cod		.0000101***	
	Pollock			.0000119***
Single Species Catcher Processor Production	Arrowtooth	.0000275***		
	Pacific Cod		.0000104***	
	Pollock			.0000362***

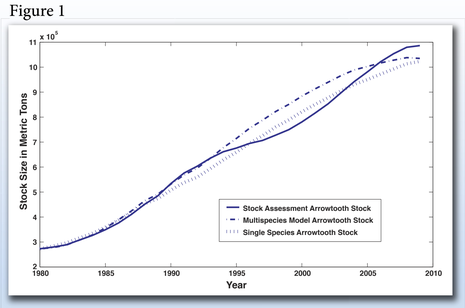
Table 2. Iterative three stage least squares regression results of catchability and bycatch coefficients of annual effort on annual catch at the vessel level. * denotes statistically significant at the 10% level. ** denotes statistically significant at the 5% level. *** denotes statistically significant at the 1% level.

RESULTS

Using the population estimates and catch levels from the 2008 SAFE reports for these three species, **Figures 1**, 2, and 3 provide a retrospective analysis of the single species, and multispecies model relative to the population estimates from the stock assessment for arrowtooth flounder, Pacific cod, and pollock respectively. The multispecies model is much more accurate in determining the stock dynamics for Pacific cod and pollock, while all three are similar for arrowtooth flounder.

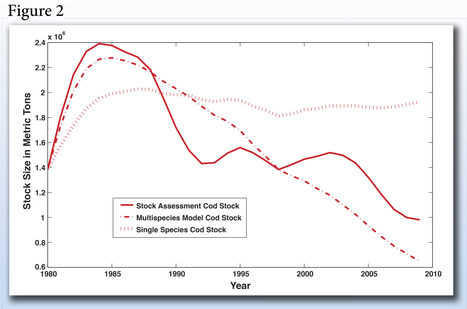
The stock size and harvest level of each species from the simulation results are presented in **Figures** 4 and 5, respectively. What is clear from **Figures** 4 and 5 is that the single species model overestimates the growth rate of pollock and cod, which leads to a higher catch levels. Incorporating technological interactions has a lesser effect on the outcome of the stock. **Figure 6** shows that, unlike Pacific cod, arrowtooth flounder and pollock harvest levels are substantially different for each type of harvesting model, indicating that technological interactions matter even when the same stock dynamics are used.

Figure 1



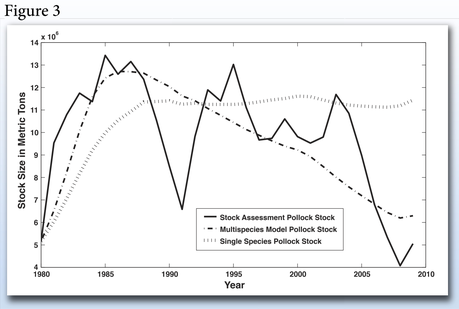
Retrospective analysis of the single and multispecies stock dynamics equation for Arrowtooth Flounder.

Figure 2



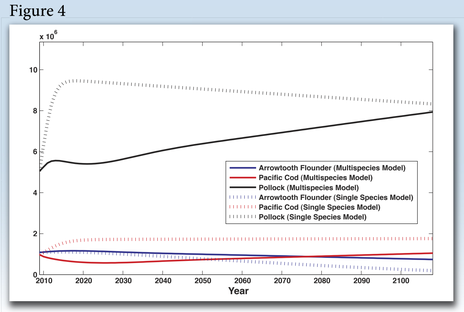
Retrospective analysis of the single and multispecies stock dynamics equation for Pacific Cod.

Figure 3



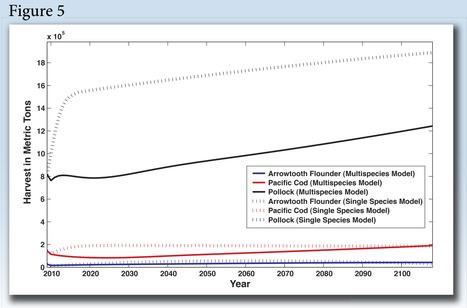
Retrospective analysis of the single and multispecies stock dynamics equation for pollock.

Figure 4



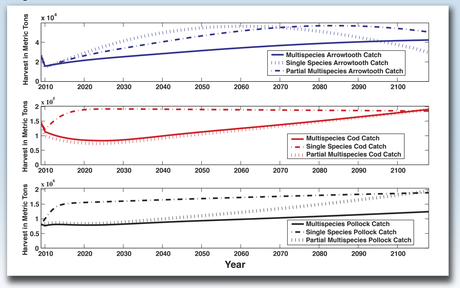
Simulated single and multispecies stock levels for Arrowtooth Flounder, Pacific Cod, and Walleye pollock.

Figure 5



Simulated single and multispecies harvest levels for Arrowtooth Flounder, Pacific Cod, and Walleye pollock.

Figure 6



Harvest levels under the single species model, multispecies model, and a partial multispecies model which uses the multispecies stock dynamics equations, but the single species productivity and effort dynamic equations.

CONCLUSIONS

This study uses a simple model of multispecies stock dynamics and multispecies harvesting to examine the role of biological and technological interactions in a three species fishery. The results suggest that for this system, the single species growth rates and harvest levels are higher than their multispecies equivalents. This implies that using the single species parameters in management may lead to a higher total allowable catch than under a multispecies alternative.

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