Estimation of total phosphorus and nitrogen waste during a 20-month grow-out period for Puget Sound Atlantic salmon net pen aquaculture facilities.

Nick Gayeski
Wild Fish Conservancy
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The amounts of nutrient waste in the form of phosphorus (P) and nitrogen (N) compounds that are released to the surrounding aquatic environment in Puget Sound by current net pen farmed Atlantic salmon aquaculture operations in Puget Sound is important to the health of the Sound. However, there appears to be little rigorous monitoring and estimation of these nutrient discharges. Any that may be done is not well reported to the public. To help Wild Fish Conservancy in our efforts to address this issue, we contracted with Dr. Ray Canale to provide an Excel spreadsheet model that can be used to calculate total phosphorus and nitrogen loads resulting from the net pen growth of Atlantic salmon. Dr. Canale is Emeritus Professor, Department of Civil Engineering, University of Michigan, Ann Arbor. He is an expert in bioenergetic modeling, including modeling of salmonids, and is widely published on water quality issues related to freshwater and marine aquaculture, including several major recent publications in the journal Aquaculture.

I employed the spreadsheet model to estimate the total phosphorus and nitrogen loads to the environment from feeding and growth of Atlantic salmon raised in all seven Puget Sound net pens facilities, if each facility started grow-out operations in the same month after fallowing and grew fish to adulthood over a 20 month period. Based on information from the Puget Sound aquaculture industry, the average length of time to raise 100 gram Atlantic salmon smolts to a target harvest size of 5500 grams (5.5 kilograms, approximately 12.1 pounds) ranges from 18 to 24 months. There is some evidence that the grow-out period can occasionally take less than 18 months under favorable conditions, so 20 months seems a conservative average period of time to use. However, the actual length of the grow-out period will not affect the total P and N loads produced, only the individual monthly totals.

The model employs standard equations for growth in weight of fish from initial average starting weights to final target harvest weight based on estimated average lipid and protein composition of Atlantic salmon muscle tissue. Based on literature values recommended by Dr. Canale, I

assumed that phosphorus made up 1.5% of the food and protein 48.2% of the food. The model requires an estimate of the percentage of food uneaten each month, and the feed conversion ratio (FCR, weight of food fed/weight of fish gained, an estimate of the average efficiency of the fish in converting food that is eaten into fish flesh), and the average monthly mortality of fish in the pens. The model calculates growth including and the amounts of P and N incorporated into fish tissue during growth together with metabolic losses, and estimates the amounts of phosphorus and nitrogen lost to the environment by metabolic processing, assuming values for the energy density of feed, the FCR, monthly mortality of fish, and the percentage of uneaten food per month.

I used monthly data for total weight of fish and total weight of feed in each facility during grow-out operations as reported to Washington Department of Ecology in monthly National Pollution Discharge Elimination System (NPDES) permit reports for the period from November 2015 to August 2017. Based on the reported monthly total weights of fish in these reports, not all net pen facilities grow fish continuously from the introduction of smolts to final harvest without removing some fish partway through the grow-out period or, perhaps adding fish during the period. Hence, it was not possible to follow a complete grow-out cycle from reported monthly data for any facility except one of the facilities (Deepwater Bay 3). So I chose to identify the largest total weight of fish in each facility within the last year (August 2016 to August 2017) and used that total weight as the final adult weight, and then used the model to calculate the total loads of P and N discharged to the environment at the end of a 20 month grow-out period that began with 100 gram smolts.

Given the value of the FCR assumed in the model, the start weight (100 grams) , the end weight (5500 grams), the number of adults in the final month, and the assumed monthly fish mortality, the model first calculated the total number of 100 gram smolts required to produce the total number of 5500 gram adults 20 months later. The free parameter for monthly percent uneaten feed was then calculated by comparing the total amount of feed in the final month reported in the NPDES permit report to the total amount calculated by the model if no feed was uneaten.

Results

The Results are presented in Table 1.

TABLE 1. Results of modeled total phosphorus (P) and nitrogen (N) loads discharged to the waters of Puget Sound by each Puget Sound farmed Atlantic salmon net pen facility based on data for month of largest total fish weight and reported total amount of feed during the final month of growth calculated from the bioenergetic model-based spreadsheet program. Number in parentheses in column 1 is the month/year with the greatest total weight of fish reported in monthly NPDES permit reports during the period of operations from August 2016 to August 2017.

Facility	*Total weight 20 mo growout (lbs.)*	*Total # Fish @ 5500 g (12 lbs.)*	*Total P Load (lbs.)*	*Total N Load (lbs.)*
Deepwater Bay 1 (7/17)	1,942,831	161,903	42,569	199,362
Deepwater Bay 2 (7/17)	2,844,131	237,011	44,371	199,770
Deepwater Bay 3 (7/17)	4,069,054	339,088	62,185	279,215
Hope Island (7/17)	1,071,649	89,304	41,998	204,978
Clam Bay (3/17)	6,503,598	541,967	132,350	615,289
Fort Ward (7/17)	1,171,326	97,611	36,875	177,715
Orchard Rocks (7/17)	2,784,905	232,075	83,688	402,087
Port Angeles (8/16)	4,951,305	412,609	110,208	516,905
TOTAL	25,338,799	2,111,567	554,244	2,595,321