MODELLING BIOACCUMULATION OF PCB TEQ LEVELS IN FARMED SOUTHERN BLUEFIN TUNA (*THUNNUS MACCOYII*)

Phua, STG[1],Daughtry, BJ[2], Davey, KR[1]

[1]Food Research Group, School of Chemical Engineering and Aquafin Cooperative Research Centre, The University of Adelaide, Adelaide 5005, South Australia, Australia; [2]Food Safety Research, South Australian Research and Development Institute and Aquafin Cooperative Research Centre, Glenside 5065, South Australia, Australia

Introduction

Southern Bluefin Tuna (SBT) (*Thunnus maccoyii*) is the major fish species aquacultured for export from Australia. Frozen and fresh chilled SBT are exported to sushi and sashimi markets in Japan (and more recently to China, United States and Korea). In 2001/02, 9245 tonne of exported farmed SBT contributed a gate value of $260.5 million.

SBT are typically caught in the Great Australian Bight between December and February (austral-summer) and towed in specially designed pontoons to the farming area offshore of Port Lincoln, South Australia. These wild-caught SBT are transferred to farm pontoons and fattened. Final harvest of a farming season usually occurs in August (austral-winter). Farmed SBT are fed a mixture of local and imported baitfish species that have a range of levels of chemical residues. Significant literature[1,2] exists highlighting the benefits of humans consuming fish (especially fatty fish for omega-3 properties), however, the presence of chemical residues in fish has drawn equal attention[3,4].

Presently, the Australian SBT industry would like to optimise fat and protein levels in farmed SBT with consequent lowest levels of chemical residues. To do this, it is necessary to understand the bioaccumulation of chemical residues in farmed SBT from baitfish sources throughout a fattening season – from transfer to harvest. These residues include polychlorinated biphenyls (PCBs). Padula *et al*. reported the levels of PCBs and dioxins for farmed SBT at harvest.[5]

Here we investigate and report on modelling bioaccumulation of PCB TEQ levels in farmed SBT.

Materials and Methods

Wild-caught SBT were pursed-seined in March 2005 in the Great Australian Bight and towed to Port Lincoln, South Australia. A total of 220 SBT were tagged, measured for fork length and weighed prior to transfer to a commercially operating pontoon of 32 m in diameter.

Experimental Design. This experiment was designed to investigate the effects on farmed SBT by increasing fat levels in a composition of baitfish throughout an 18-week season. Target fat levels for the feed for each of the three 6-week experimental periods were: 4, 7.5 and 10.5 % w/w. This was achieved by changing the ratios of three baitfish species (Australian sardines, *Sardinops neopilchardus*; Australian red bait, *Emmelichthys nitidus nitidus* and Californian sardines, *Sardinops sagax*) with known nutritional profiles, fed to the SBT. The quantity of baitfish (kg) fed was recorded daily. An applied assumption is that the feeding rate is proportional to the weight of SBT fed (David Ellis, *pers. comm.*).

Chemical Analyses. A 6-week period composite for each of the baitfish species and a composite of individually blended cuts (skin-off and dark red meat removed) for each farmed SBT was wrapped in aluminum foil, frozen (-80^{o}C) and transported to AgriQuality in Wellington, New Zealand. Samples were analysed for PCBs in accordance with USEPA protocol Method 1668A (Isotope Dilution). PCBs levels were quantified using a high resolution-gas chromatography mass spectrometry. Upperbound results were reported in picogram of PCB per gram of fish flesh (parts per trillion) fresh weight. PCB TEQ values were determined according to Van den Berg *et al.*[6] using human TEF values.

Modelling Techniques. Using engineering principles, a model for bioaccumulation of residues in the flesh of SBT can be formulated based on the work of Sijm *et al.*[7]:

$$\frac{dC_{SBT}}{dt} = \eta F C_{bait} - \left(k_e + k_b + k_g\right) C_{SBT} \quad (1)$$

where C_{SBT} is the PCB TEQ level in a farmed SBT (pg/g), η is the uptake efficiency of food, *F* is the feeding rate (kg baitfish kg SBT^{-1} $time^{-1}$), C_{bait} is the PCB TEQ level in baitfish (pg/g), k_e, k_b and k_g are, respectively, rate constants for elimination, biotransformation and growth ($time^{-1}$). Assuming that the elimination and biotransformation rates are negligible for this short farming season and integrating Equation (1) gives:

$$C_{SBT,t} = \frac{\eta F}{k_g} C_{bait} \left(1 - e^{-k_g t}\right) + C_{SBT,t_0} e^{-k_g t} \quad (2)$$

Non-linear regression of Equation (2) for PCB TEQ levels against time was used to estimate η and C_{SBT,t_0} .

Results & Discussion

Figure 1 presents a plot of whole (estimated catch) weight of farmed SBT against time at harvest. The average weight at transfer into the sea cage was 19.76 kg increasing to 30.28 kg at 18 weeks. The average weight increase between weeks 12 and 18 is 1.24 kg - compared with 4.8 kg between transfer and week 6. This difference of some 3.6 kg is most likely due to the decrease in water temperature during the winter months.

Figure 2 presents a plot of the apparent daily feed intake per kg of SBT per day for each of the experimental periods: 1, 2 and 3. Whilst SBT are feeding during Period 3, weight increase is minimal between weeks 12 and 18 (Harvest 2 and 3) (*see* Figure 1). The feeding during Period 3 occurs at a rate one-third that of Period 1, where water temperatures were higher - also a likely consequence of declining water temperatures throughout the experiment.

The PCB TEQ level for the Australian baitfish species is $1/6^{th}$ that of Californian sardines. Table 1 presents PCB TEQ levels for Australian sardines & red bait and Californian sardines together with the average lipid content corresponding with experimental periods.

Figure 3 is plot of fresh weight PCB TEQ levels in the edible portion of farmed SBT against days following transfer from the tow to the farm pontoons. At transfer (day 0), the average TEQ level of wild-caught SBT is 0.12 pg-TEQ/g (range 0.0738 pg-TEQ/g to 0.153 pg-TEQ/g). This level is lower than that in juvenile Northern Bluefin Tuna from Mediterranean seas[8]. In Figure 3 the solid line represents the predicted values of the bioaccumulation model. Non-linear regression of Equation (2) using population averages for *F* and k_g yields regression estimates of η = 0.52 (standard error = 0.071) and C_{SBT,t_0} = 0.18 (standard error = 0.048).

Opperhuizen and Schrap[9] studied 2,2'3,3',5,5' Hexa-CB and 2,2',3,3',4,4',6,6' Octa-CB in guppies and concluded generally that for low dietary exposure, it is feasible to use η = 0.50 for all hydrophobic chlorines and aromatic hydrocarbons. Values of η = 0.67 to 0.85 for WHO TEF-assigned congeners for salmon have been reported (Marc Berntssen, *pers. comm.*) Our finding of η = 0.52 is based on (i) PCB TEQ (i.e. not individual congeners) and (ii) on fillets (i.e. not whole fish that includes internal organs). On the basis where whole fish it would be expected that higher uptake efficiencies. This is the first time uptake efficiency and PCB TEQ levels through farming time have been modelled for farmed SBT.

Equation (2) represents the minimum for a model of bioaccumulation of residues. Additionally, it has been assumed that the feeding behaviour and growth of sampled SBT is the same as that of the population in the pontoon.

If these assumptions do not hold for an individual SBT, it would be expected that inaccuracies in predictions will increase. It is important therefore further work be carried out work to investigate the sensitivity of these assumptions on ultimate model predictions.

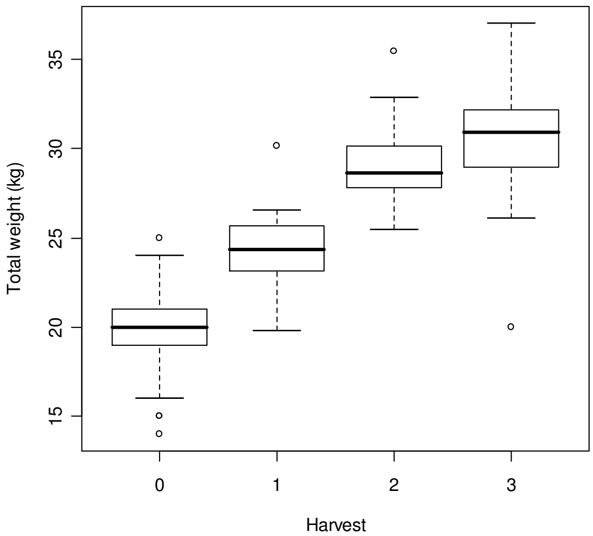

Figure 1. Box and whisker plot of whole weight of wild and farmed SBT at transfer (harvest 0), 6, 12 and 18 weeks after the start of the experiment (harvests 1-3).

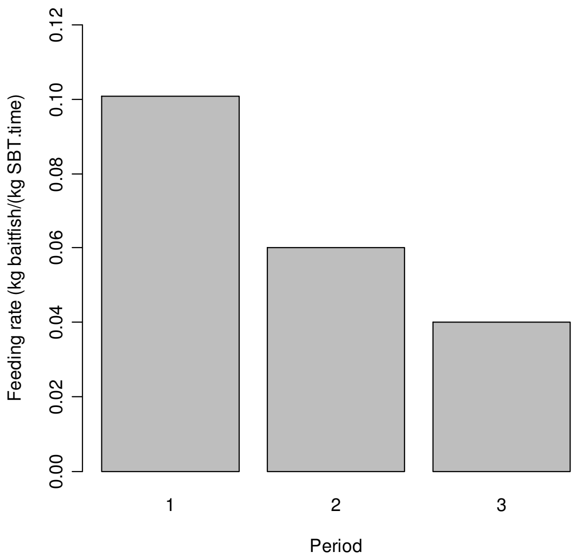

Figure 2. Apparent feeding rate for farmed SBT for each 6-week period of the experiment.

Table 1. Three species of baitfish with fresh weight PCB TEQ levels corresponding to the three experimental periods 1,2 and 3 (0-6, 7-12, 13-18 weeks).

Baitfish	Lipid Content (%)	Experimental Period	PCB TEQ Level (pg-WHO TEQ/g)
Australian sardines	2.7	1	0.0512
		2	0.0563
		3	0.0774
Australian red bait	4.3	1	0.0581
		2	0.0540
		3	0.0517
Californian sardines	14.3	1	0.331
		2	0.320
		3	0.364

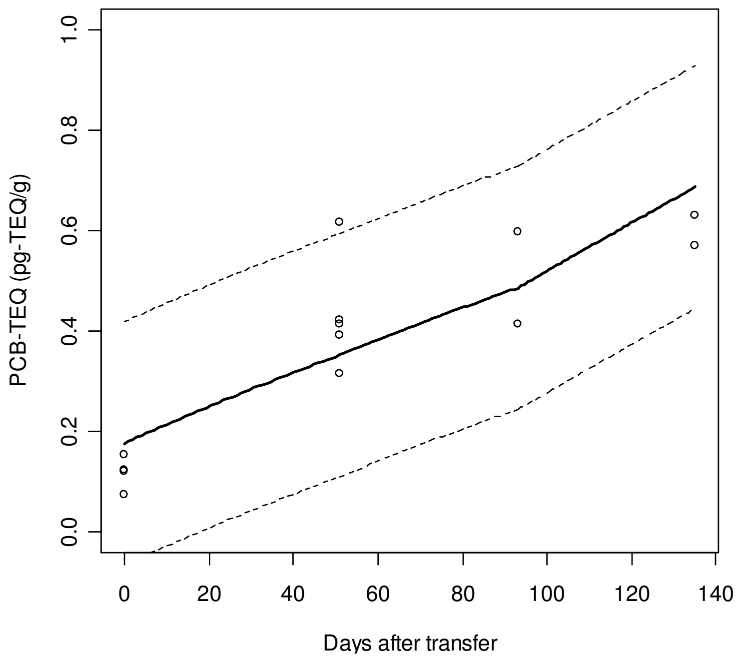

Figure 3. PCB-TEQ levels following transfer of SBT from the tow pontoons (wild-caught) to the farm pontoon. The solid line is the model predictions and the dashed lines are the 95th confidence interval based on the residual standard error.

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