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Empirical models to identify mechanisms driving reductions in tissue mercury concentration during culture of farmed southern bluefin tuna *Thunnus maccoyii*

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ABSTRACT

Two empirical models are presented to elucidate the mechanisms driving reductions in the mercury concentration of southern bluefin tuna (SBT) during culture. Model 1 predicts temporal fluctuations in mercury concentration in response to growth dilution. Model 2 predicts the combined effects of growth dilution and linear mercury accumulation. Model 2 was found to be the more accurate model. Over a typical farming period of 136 days, growth dilution resulted in a reduction in mean mercury concentration of SBT edible tissues from 0.51 mg/kg down to 0.33 mg/kg. Extended culture beyond 136 days resulted in an increase in mercury concentration due to the combined effects of mercury accumulation and seasonal lipid depletion. Results indicate that under current industry practice, cultured SBT can be consumed twice as frequently as that of wild caught SBT while maintaining total dietary mercury intake below national recommendations.

1. Introduction

Methyl mercury is recognised as a naturally occurring, neurotoxic metal residue that has the potential to accumulate to toxic levels in fish tissues – the primary environmental source of human mercury exposure (Tchounwou et al., 2003). The cumulative nature of methyl mercury results in those fish that are older and of higher trophic level being typically found to have the highest mercury content, and potentially pose the greatest threat to human health (Balshaw et al., 2007). Amongst those species recognised as potentially accumulating elevated mercury levels, tuna are one of the most frequently consumed and commercially available groups of fish worldwide (e.g. Food Standards Agency, 2002; Burger et al., 2005). Levels of mercury in tuna vary according to species (Storelli et al., 2002), size (Peterson et al., 1973) and geographic location (Bernhard and Renzoni, 1977). Moreover, preliminary monitoring of mercury concentrations in Australian wild caught and farmed southern bluefin tuna, *Thunnus maccoyii* (SBT) indicate a reduction in mercury concentration under culture conditions (Padula et al., 2003, 2004a).

Culture of the SBT (Glencross et al., 2002) and also other tuna species including the northern bluefin tuna, *Thunnus thunnus* (Aguado-Gimenez and Garcia-Garcia, 2005) and bigeye tuna, *Thunnus obesus* (pers com, Steven Clarke, SBT sub program Leader, SARDI), is based on the transfer of wild caught fish to sea pontoons where they are cultured under intensive fattening conditions for a period of several months before harvest. Within Australia the SBT fishery operates annually, based on the capture of juvenile SBT aged 1–5 years (85–120 cm fork length), which congregate in the Great Australian Bight between November and July (Leigh and Hearn, 2000). Culture typically lasts 6–8 months during austral autumn and winter. Harvests occur throughout the culture period, with all fish typically being harvested by August each year in order to take advantage of the species seasonal weight gain (Glencross et al., 2002). In recent years, however, the SBT aquaculture industry has considered longer term holding strategies for cultured tuna in Australia. This would give the industry flexibility to supply overseas markets at different times of the year and take advantage of supply shortfalls elsewhere in the global market.

While the primary aim of this form of farming is to rapidly increase the biomass and lipid content of tissues, farming may also provide producers with a unique opportunity to manage mercury residue levels. It has been well established that, amongst carnivorous fish such as tuna, mercury content tends to increase with size as a function of age (Peterson et al., 1973; Storelli and Marcotrigiano, 2001; Kojadinovic et al., 2006). However, while mercury

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concentration typically increases throughout the life of the fish, over shorter time periods the concentration of mercury in fish tissues has the potential to fluctuate in response to seasonal changes in tissue growth rate, feeding rate, and feed sources – any factor which can alter the ratio between the total burden of mercury and the quantity of fish tissues (Gilmartin and Revelante, 1975; Monteiro and Lopes, 1990; Futter, 1994; Dorea et al. 2006). Consequently, in addition to feed choices, the timing and duration of culture can significantly affect the mercury concentration in fish tissues at harvest.

Here, we extend the observations of Padula et al. (2003, 2004a), which suggested a reduction of mercury concentration during culture of SBT over a single commercial farming season of 6 months. We aim to identify the mechanisms driving observed reductions in mercury concentration of fish tissues. Two potential mechanisms are proposed. Firstly, farmed SBT may have a reduced mercury concentration due to the fattening process causing growth dilution of mercury residue associated with fish tissues. Secondly, selection of feed sources could result in mercury excretion occurring at a rate faster than that of mercury accumulation, resulting in a net decrease of mercury residue in fish tissues. In order to fully understand the effects of culture on mercury concentration in farmed tuna, we report on the temporal fluctuations in SBT growth kinetics, total mercury burden (net load of mercury in fish tissues expressed in mg) and mercury concentration (expressed as mg of mercury per kg of tissue). Two empirical models are developed to illustrate the cause of observed fluctuations in mercury concentration during culture. Data collection and model predictions extend throughout a culture period of one commercial farming season with an additional experimental period of approximately 12 months. This extended culture was carried out in order to elucidate any seasonal trends that may be occurring, and to understand the impacts of longer term holding strategies on the accumulation of mercury residue in harvested SBT. Results are evaluated in terms of the effects of current and longer term holding farming strategies on mercury content of SBT tissues and the consequences for consumer health.

2. Materials and methods

2.1. Experimental design

SBT were purse-seined by commercial vessel in the Great Australian Bight in March 2005. Over several weeks, SBT were towed to the coastal waters of Port Lincoln, where they were tagged with individual identification numbers and their lengths recorded, before being transferred into commercially operated experimental culture pontoons.

During the commercial farming season from March to August 2005, four harvests were made from each of two experimental pontoons, the first at transfer of SBT into sea pontoons on 8 April 2005 (day 0); then at 52 days culture on 30 May 2005; 94 days culture on 11 July 2005; and at 136 days of culture on 22 August 2005.

During this time fish were fed a mixture of Australian and imported baitfish species to apparent satiation, twice daily, six days a week (weather permitting). Baitfish species included Californian sardine (*Sardinops sagax*), Australian redbait (*Emmelichthys nitidus nitidus*) and Australian sardine (*Sardinops neopilchardus*). Each pontoon was fed an individual baitfish diet as part of a collaborative research project (involving a total of four pontoons). A sequential cross over design was used in which diets were changed after each experimental harvest. The proportions of different baitfish species in diets were manipulated to control levels of fat and protein.

Following completion of the commercial farming season, all remaining fish were pooled into a single pontoon and held for an additional 12 months culture until August 2006. Again fish were fed to apparent satiation, twice daily, six days a week (weather permitting). Baitfish species fed during this time included Californian sardine, Australian redbait, Australian sardine, Indonesian herring (*Sardinella lemuru*) and blue mackerel (*Scomber australasicus*).

During this extended experimental culture period, three harvests were made for research purposes, the first after a total of 243 days culture on 7 December 2005; then after a total of 355 days culture on 29 March 2006; and at completion of the experiment after a total of 494 days culture on 15 August 2006. Three additional commercial harvests were also made in March 2006 at 333, 340 and 348 days culture.

At completion of the experiment a total of 470 SBT was harvested with intact tags and used for analysis of SBT growth (length and weight). Of these, 50 were collected for residue analysis; 5 SBT at transfer into culture pontoons (day 0), 10 SBT each at 55, 97 and 139 days culture; and 5 SBT each at 246, 355, and 494 days culture. SBT were harvested in equal numbers from each of the two experimental pontoons during the first 139 days culture. All SBT were pooled into the one pontoon for the extended culture phase (days 137–494), thereafter all SBT were sampled from the one pontoon, which included representatives from each of the initial pontoons and diet regimes. Harvest information is presented in Table 1.

All fish were harvested in accordance with normal commercial operational procedures (see Hayward et al., 2007) and were received eviscerated and bled, either frozen or fresh chilled as per export bound product.

Table 1
Total number of SBT harvested for analysis and for residue analysis throughout the experimental period from April 2005 until August 2006

Harvest date	Culture time (days)	Culture phase	*n*	
			Total harvested	Residue tested
05 April 2005	0	Commencement of commercial farming season	115	5
30 May 2005	52	Commercial farming season	18	10
11 July 2005	94	Commercial farming season	58	10
22 August 2005	136	Completion of commercial farming season	57	10
07 December 2005	243	Experimental, extended culture phase	27	5
7 March 2006	333	Experimental, extended culture phase	26	0
14 March 2006	340	Experimental, extended culture phase	57	0
22 March 2006	348	Experimental, extended culture phase	51	0
29 March 2006	355	Experimental, extended culture phase	40	5
15 August 2006	494	Experimental, extended culture phase	21	5