Tuna transport of Fukushima-derived radiocesium across the North Pacific, and application to improved understanding of trans-Pacific migration rates

Daniel J Madigan, Zofia Baumann*, Nicholas S Fisher

SoMAS, Stony Brook University, Stony Brook, NY 11794

Introduction

The Fukushima accident released radionuclides directly into the West Pacific Ocean. The dominant long-lived gamma-emitting radionuclides ^{134}Cs ($t_{1/2}$ = 2.1 yrs) and ^{137}Cs ($t_{1/2}$ = 30 yrs) were released at a consistent ratio of ~1, and after 2 to 3 months surface concentrations still exceeded prior concentrations by up to 1,000-fold over a 150,000 km^2 area of the Pacific east of Japan.

The Pacific bluefin tuna (*Thunnus orientalis*; PBFT) inhabits the West and East North Pacific Ocean. Mature PBFT spawn in the West Pacific, and some juveniles remain in Japanese waters while others migrate eastward to the California Current Large Marine Ecosystem (CCLME) (Fig. 1). PBFT were assessed as a highly depleted species in 2012, making assessment of their migratory cycle and associated regional mortality a priority.

We tested that juvenile PBFT served as biological vectors of radionuclides by analyzing muscle for the presence of Fukushima-derived radiocesium. We then tested the efficacy of the radiocesium tracer by comparing it to stable isotopes of carbon and nitrogen. Finally, we combined these methods to assess migration dynamics in a large samples set of Pacific bluefin tuna in the CCLME (n = 428), and with similar approaches and results from the West Pacific, assess the overall proportion of PBFT that are likely to migrate to the CCLME at some point in their life history.

Materials and methods

In 2011, 15 juvenile (<70 cm) PBFT were sampled off San Diego, CA, USA. Muscle tissue was collected to test for the presence of ^{134}Cs and ^{137}Cs using gamma-spectroscopy. Samples of pre-Fukushima (2008; n = 5) PBFT and post-Fukushima yellowfin tuna (2011; n = 5) were also analyzed to validate Fukushima as the source of detected radiocesium.

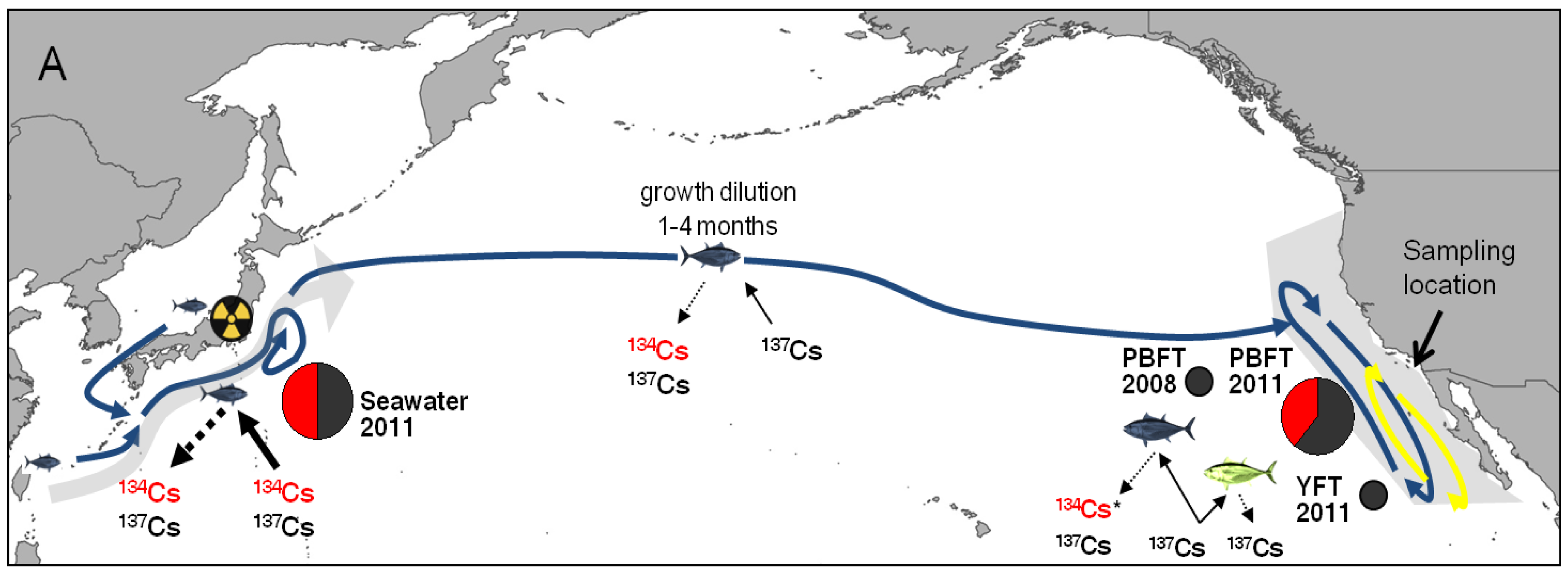
On a larger dataset of PBFT, we tested for the presence of radiocesium in PBFT collected in 2012 and 2013. We compared results to SIA of δ^{13}C and δ^{15}N to validate the new tracer.

We applied SIA of δ^{13}C and δ^{15}N to PBFT spanning ages 1 – 7 to assess trans-Pacific migration, residency, and migration timing in PBFT in the CCLME.

We combined SIA results with those in the EPO to assess the proportion of PBFT that use the CCLME at some stage of their life.

Results

1. **All analyzed (n=15) PBFT carried Fukushima-derived radiocesium across the North Pacific Ocean in 2011 (Figure 1).**
2. **Detectable ^{134}Cs in all PBFT <1.7 years old, and in some age 1.7 to 2.5 years old, suggested that all PBFT migrate across the Pacific in the first years of life.** This dataset validated the efficacy of the radiocesium tracer, and that of SIA of δ^{13}C and δ^{15}N.
3. **Applying δ^{13}C and δ^{15}N to 428 PBFT, along with radiocesium, demonstrated on a larger scale that no PBFT migrate across the Pacific at >2.5 years of age.** This indicates that older (7 – 8 years old) PBFT reside in the CCLME for at least 4 - 5 years, making mortality in the CCLME impactful on growing fish.
4. **Combined with δ^{13}C and δ^{15}N results in the West Pacific, we showed that a majority of PBFT use the CCLME.** This makes management in the CCLME a priority rather than previous inferences of negligible proportions.



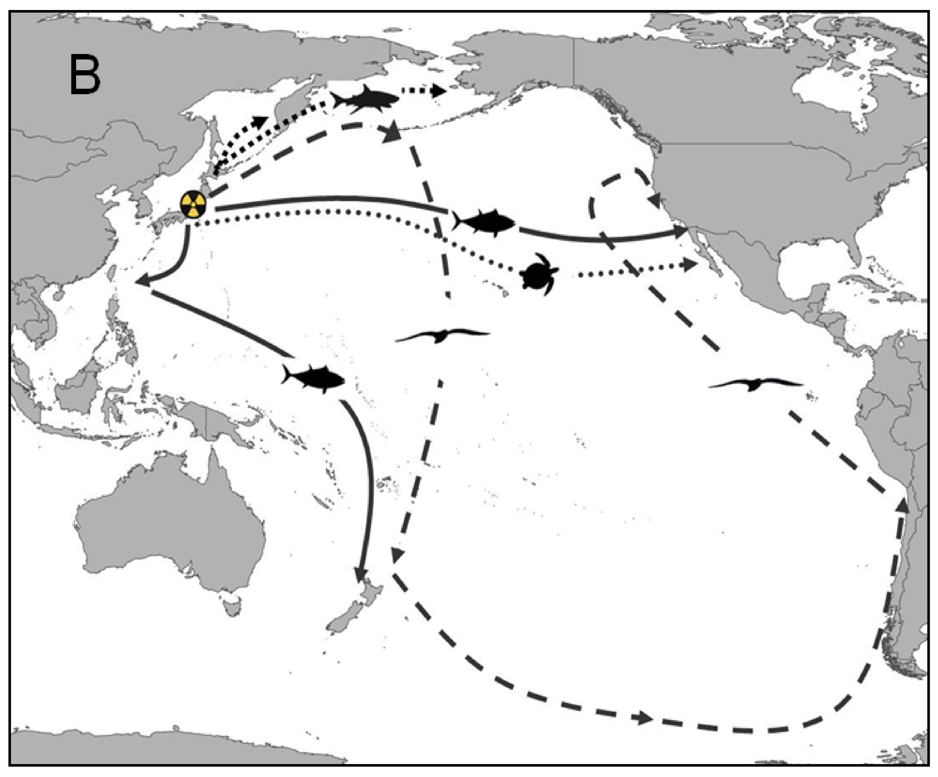


Figure 1. Pacific bluefin tuna transport Fukushima-derived radiocesium across the North Pacific Ocean in 2011. (A) All Pacific bluefin tuna sampled off San Diego, CA, USA in 2011 (n = 15) had measurable ^{134}Cs and elevated ^{137}Cs compared to background concentrations. Pre-Fukushima bluefin and post-Fukushima yellowfin in the East Pacific had undetectable ^{134}Cs and background ^{137}Cs levels, indicating Fukushima as the unequivocal source of radiocesium in bluefin tuna. This presented the possibility that **(B)** radiocesium from Fukushima could serve as a transient chemical tracer of pelagic animal movements away from eastern Japan waters, including sharks, seabirds, turtles and fish. From Madigan *et al* (2012) *PNAS*.

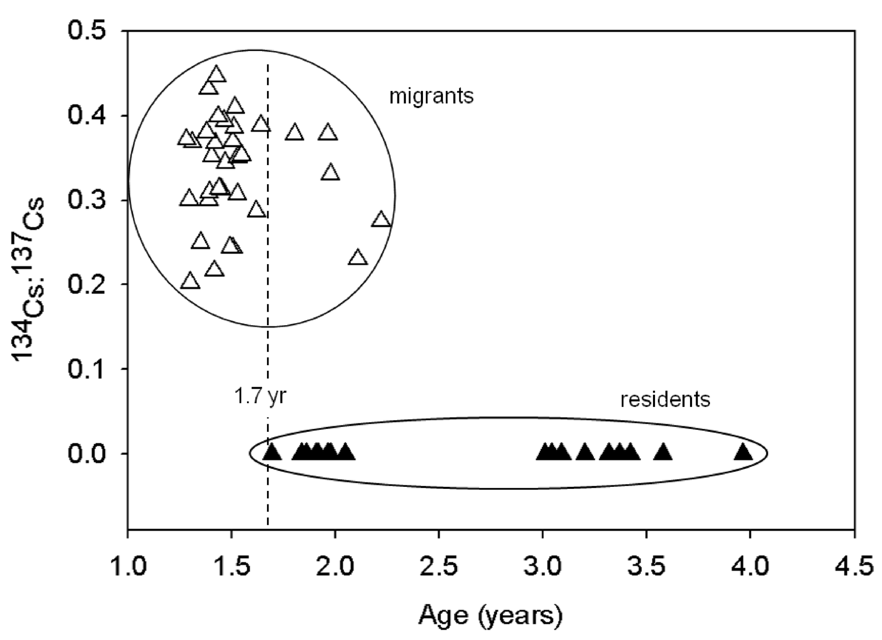


Figure 2. Validation of the radiocesium tracer for trans-Pacific migrations of Pacific bluefin tuna. Results (a) validated the tracer efficacy and (2) demonstrated radiocesium transport in the youngest PBFT. From Madigan *et al* (2013) *ES&T.*

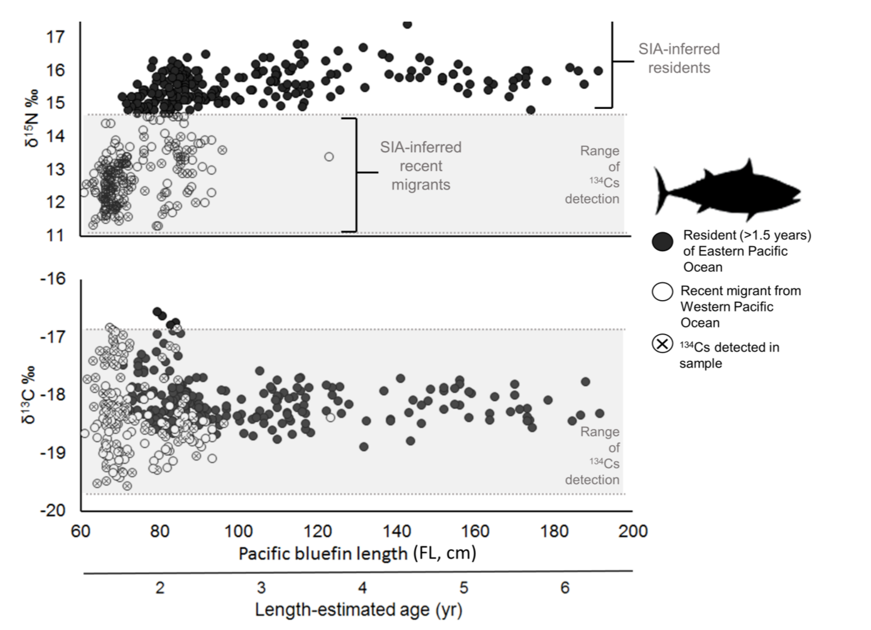


Figure 3. Combining radiocesium and stable isotope analysis (δ^{13}C and δ^{15}N) shows that Pacific bluefin tuna migrate from the West to East Pacific Ocean in their first 1 – 2 years of life. Older PBFT in the East Pacific are thus subject to fishing pressure in the region for multiple years. From Madigan *et al* (2017) *CJFAS.*

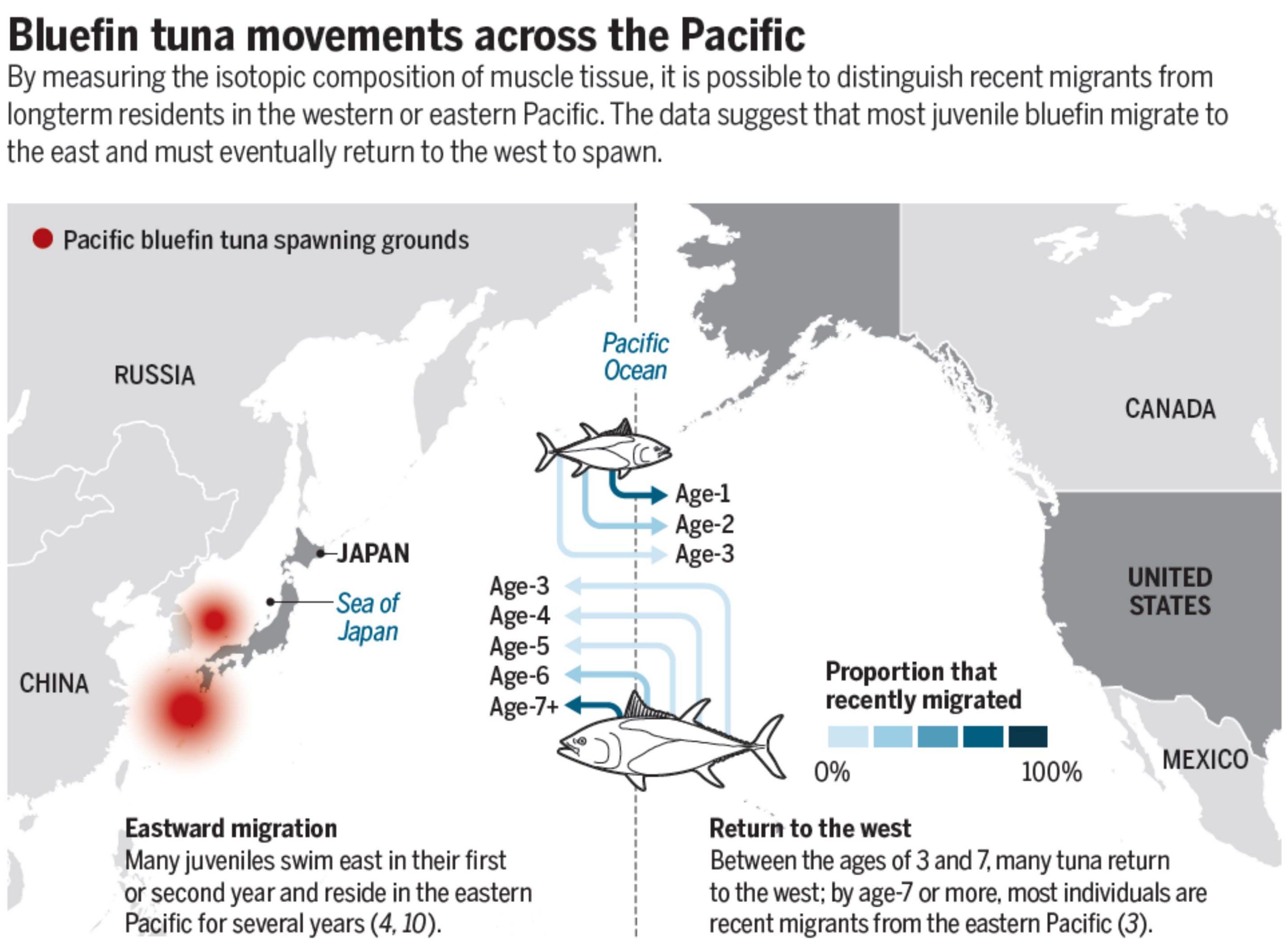


Figure 4. Combined SIA on both sides of the North Pacific showed that the majority of PBFT use the East Pacific Ocean at some stage of their lives. This was previously considered a minority and makes management in the East Pacific a priority for an overfished species. From Madigan *et al* (2017) *Science*.

Conclusions

1. **A pelagic fish served as a transport vector of Fukushima radionuclides from the West to East Pacific.** This presented the possibility of a new chemical tracer of trans-Pacific movements.
2. **Radiocesium showed that stable isotopes of C and N can track PBFT migrations *ad infinitum* as a naturally occurring tracer.**
3. **All PBFT migrate to the East Pacific in the first 2 years of life.** Larger fish face fishing mortality in the East Pacific for years before returning West.
4. **Combined with SIA in the West, tracers show that the majority of PBFT uses the East Pacific.** Formally considered a minority, this makes management in the East a priority.

Literature cited

- **Madigan DJ**, Baumann Z & NS Fisher. 2012. Pacific bluefin tuna transport Fukushima-derived radionuclides from Japan to California. *PNAS* 109(24), 9483-9486.
- **Madigan DJ**, Baumann Z, Snodgrass OE, Ergül HA, Dewar H & NS Fisher. 2013. Radiocesium in Pacific bluefin tuna *Thunnus orientalis* in 2012 validates new tracer technique. *Environmental Science & Technology* 47: 2287-2294.
- **Madigan DJ**, Baumann Z, Carlisle AB, Snodgrass OE, Dewar H & NS Fisher. 2017. Isotopic insights into migration patterns of Pacific bluefin tuna in the eastern Pacific Ocean. *Canadian Journal of Fisheries & Aquatic Sciences* 75(2): 260-270.
- **Madigan DJ**, Boustany A & BB Collette. 2017. East not least for Pacific bluefin tuna. *Science* 357(6349): 356-357.

Acknowledgments

We thank the fishermen in San Diego, CA who donated PBFT samples. S Zegers made laboratory analyses possible. SWFSC volunteers collected additional PBFT samples. This work was funded by the Moore Foundation and NOAA (to NSF), and a NSF Fellowship and HUCE Fellowship (to DJM).

For further information:

Please contact *daniel.madigan@stonybrook.edu*

NOAA

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

SoMAS School of Marine and Atmospheric Sciences

STONY BROOK UNIVERSITY