North Pacific Marine Science Organization (PICES)

# Working Group 30: Assessment of Marine Environmental Quality of Radiation around the North Pacific


## Summary

On March 11, 2011, a large magnitude 9.1 earthquake struck off the Tohoku coast of Japan, triggering large tsunami waves which struck Japan's coast, causing loss of life and significant damage. The tsunami caused an accident at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP), which released a large amount of radiation into the marine environment of the North Pacific Ocean.

In 2013, PICES formed an interdisciplinary Working Group on Assessment of Marine Environmental Quality of Radiation around the North Pacific (WG 30), to assess the impact of the 2011 Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident, by documenting and evaluating in real time the environmental changes associated with the accident. Recording impacts and consequences of a specific event as they occurred was unusual for a PICES working group, making the work of this group unique, and the WG meetings an important forum for timely exchange of new information among PICES member countries.

WG 30 focused on acquiring and sharing information from seasonal cruises undertaken by each North Pacific member country, thereby expediting the international dissemination of Fukushima monitoring data. Products of this working group include a final report, two major workshops, a PICES-SCOR invited collaborative review article and over 40 scientific publications in international peer-reviewed journals.

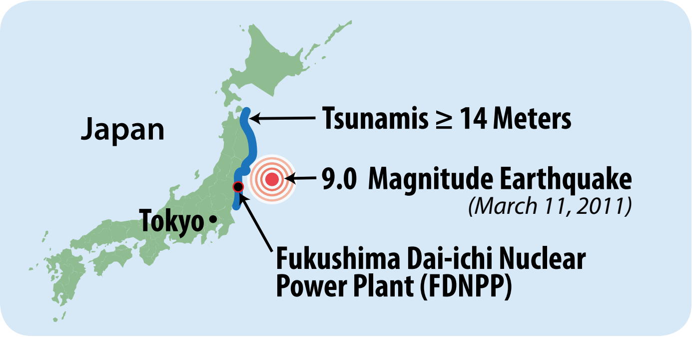
Primary accomplishments of WG 30 included the promotion of research through coordinated communications, exchange of sampling and analytical methodologies, laboratory visits and meetings, and publication of results. The principle thrust of the collaborative research was on radionuclide transport in the ocean, ocean-atmospheric exhange of radioactivity, radionuclide uptake in sediments and marine biota, and impacts on marine food webs and ecosystems.

Additionally, WG 30 tested and evaluated a range of modeling study types, including models for: radionuclide transport, fate, radiological dosing and risk assessment.

The evaluations were enhanced by the fact that the FDNPP accident represents the largest ever point-source discharge of radioactivity into the marine environment, which provided a strong input signal with far-field features particularly amenable to model validation for WG 30 experimental data.

As the 4-year lifetime of WG 30 approached, it was clear that its members had benefited from international cross-fertilization of ideas, data sharing, and cultural exhanges that were encouraged and supported under the auspices of PICES. The FDNPP accident is unlikely to be the Pacific Ocean's last nuclear incident with potentially deleterious impacts on marine ecosystems. Within the next decade, dozens of new nuclear power plants will begin operations in Asia. Furthermore, there are other possible sources and mechanisms for the discharge of large quantities of radioactivity into the marine environment. The research and products of WG 30 can serve to guide future monitoring and assessment programs for radioactivity.

Detailed information on WG 30 accomplishments is contained in the WG 30 final report, available at: https://meetings.pices.int/members/working-groups/disbanded/wg30.

## Coastal area near FDNPP

The FDNPP accident was characterized by the rapid direct release of water highly contaminated with radioactive iodine ($^{131}I$) and cesium ($^{137}Cs$ and $^{134}Cs$). The direct leakage of $^{137}Cs$ was estimated as 3.5 petabecquerel (PBq) and the highest seawater concentration (>6 x $10^4$ Bq/L) was observed in early April of 2011, at the coast near the FDNPP. This value was seven orders of magnitude higher than the pre-accident levels. Seawater concentrations of $^{137}Cs$ declined quickly following the accident owing to ocean mixing and transport in the dynamic coastal regime off eastern Japan. Within several years $^{137}Cs$ levels approached pre-accident levels (Figure 1).

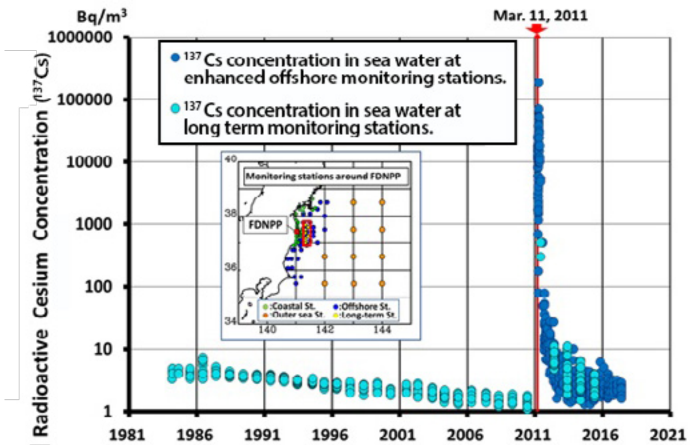



Figure 1. Combined historical and post-accident (from red rectangle region in the map) time series monitoring results for $^{137}Cs$ in seawater off Fukushima.

Analysis of marine organism monitoring data of 131,084 inspection results, at the end of June 2020, mainly from around prefectures of Fukushima showed that more than 20% of inspected samples were over the Japanese regulatory limit (100 Bq/Kg-wet for radioactive Cs) in the period immediately following the accident (April–June 2011). This percentage gradually declined and has remained at 0% since April 2015 except for February 2018 (Figure 2). Ongoing releases of $^{137}Cs$ from the FDNPP harbor were estimated to be 3 TBq/y for the summer of 2012.

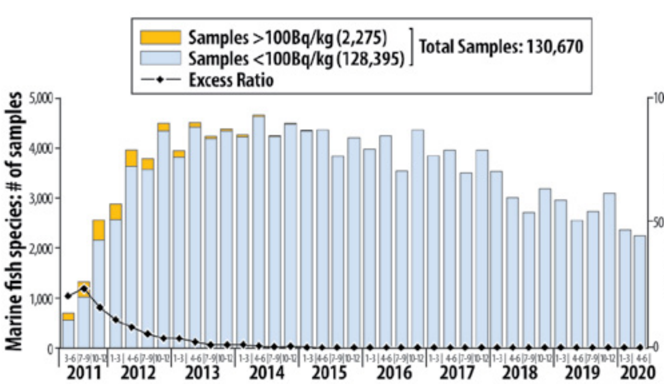



Figure 2. Fishery products summary monitoring (as of Jun 25,2020).[1]

[1] https://www.jfa.maff.go.jp/e/inspection/index.html

Because the concentration of $^{137}Cs$ in the harbor decreased by a factor of 5 between 2013 and 2016, the 2016 annual release of $^{137}Cs$ from FDNPP harbor was estimated to be 0.6 TBq/y. Monitoring results outside of the harbor have shown that the ongoing releases had no influence on the concentration of $^{137}Cs$ in marine organisms.

## Coastal Sea of Korea

Radionuclide concentrations ($^{3}H$, $^{137}Cs$, $^{90}Sr$, $^{239+240}Pu$) in the surface seawater since 2011 are consistent with the measurements obtained over 5 years (2006 –2010) prior to the FDNPP incident. Concentrations of $^{137}Cs$, $^{90}Sr$, and $^{239+240}Pu$ in ocean sediments and marine biota (fish, shellfish, and seaweed) from 2011–2016 were similar to those prior to the FDNPP accident. Conversely, concentration of $^{137}Cs$ in the flathead grey mullet (*Mugil cephalus*) from the eastern coast in 2012 was found to be 2,432 ± 32 mBq/Kg-wet. This is 10 times higher than annual average measured concentrations in fish from 2006–2011. The activity ratio of $^{134}Cs/^{137}Cs$ analyzed in mullet coincided with cesium emitted from the FDNPP event.

## Coastal sea of China

Seawater, sediment samples, and marine organisms collected in Chinese coastal waters from 2011–2015 were analyzed for a wide range of radionuclides released during the FDNPP discharge. Detectable levels of $^{134}Cs$ were found at 11 sampling sites, with the highest activity of 0.98 Bq/m$^3$, indicating that a small amount of $^{134}Cs$ was transported from the FDNPP to Chinese coastal waters.

## Northwest Pacific

Monitoring results showed that the activity of $^{134}Cs$ and $^{137}Cs$ measured in the NW Pacific from May–June 2011 was two orders of magnitude higher than fallout background levels before the accident, while the activity of $^{90}Sr$ was 25 times higher than the background. Levels of $^{137}Cs$, $^{134}Cs$ and $^{90}Sr$ in the northwest Pacific decreased quickly after the accident, but until 2016, they were still elevated compared to the background (Figure 3). Radioactivity levels in marine organisms reached maximum levels in 2012 and decreased with time thereafter. The radiological dose assessment showed the radiological dose to pelagic fish and cephalopod species in NW Pacific was far below the recommended dose limits, indicating that there were no significant harmful radiological effects on these species.

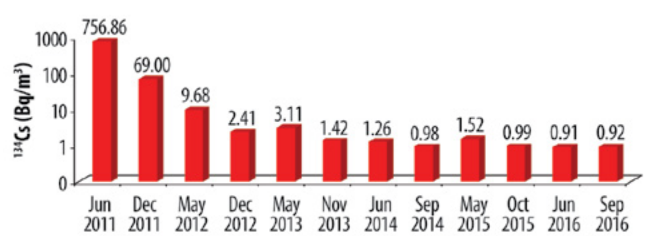



Figure 3. Time evolution of $^{134}Cs$ maximum value measured in monitoring area.

Monitoring results showed that Fukushima-derived radiocesium in surface seawater was transported eastwards to the Northeast Pacific. During this process, part of the surface radiocesium was subducted in Subtropical Mode Water (STMW) and Central Mode Water (CMW) and transported southwestwards along subsurface pathways to lower latitudes.

## Northeast Pacific

Time series measurements of $^{134}Cs$ and $^{137}Cs$ in seawater on Line P (a series of scientific sampling points off the coast of British Columbia, Canada) documented the initial arrival of the Fukushima signal by ocean current transport at a location 1500 km west of British Columbia, Canada, in June 2012, about 1.3 years after the accident. Between 2012 and 2015, the Fukushima radioactivity signal continued to increase in surface water on Line P and eventually began to level off at probable maximum values in 2016–2017 as documented by biannual monitoring surveys. Although radioactivity contamination of fish off Fukushima was initially severe, analyses of biological samples performed under the auspices of the International Fukushima Ocean Radionuclide Monitoring Network (inFORM) program off British Columbia (Figure 4), revealed little evidence of elevated radioactivity levels in fish or other biota. These results, based on both measurements and biological modeling studies (Figure 5) are a consequence of the low Fukushima radionuclide level in Northeast Pacific seawater and the low biological half-lives for Cs in fish, which results in a relatively rapid turnover of contaminants.

Although the ecosystem impacts off British Columbia associated with radioactivity releases from FDNPP have been minimal, the communication of these results to the public and general acceptance of their veracity has been a challenge which required many public lectures, scientific publications, and considerable media outreach to ameliorate. This may be used as a cautionary note for future studies of ecosystem threats associated with grim anthropogenic drivers.

## Radionuclide transfer model for food chains

The fate model (Figure 6) was developed to predict the transfer of radionuclides to marine species since 2012. The extended-BURN-POSEIDON model equipped with pelagic and benthic food webs was developed to provide an explanation for $^{137}Cs$ concentrations in benthic fish remaining at a level significantly higher than that of pelagic fish.

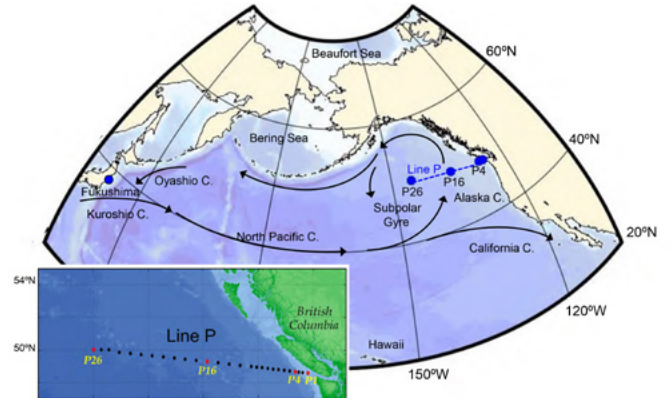



Figure 4. INFORM sampling stations on Line P in the NE Pacific.

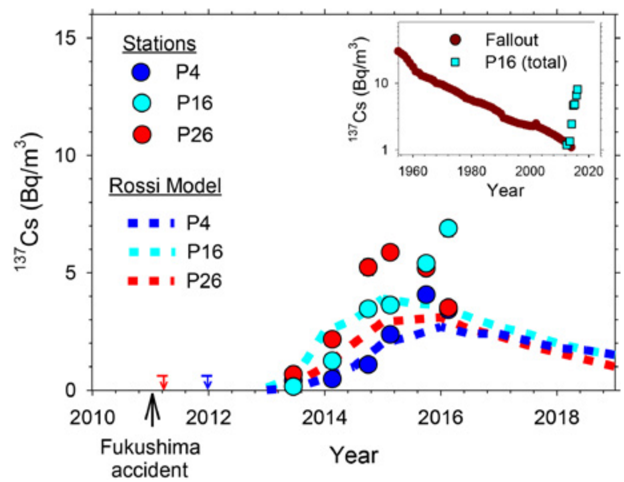



Figure 5. Model simulations time series of Rossi et al. (2014) for upper 200m compared to mean Fukushima $^{137}Cs$ concentrations in upper 150m at Stns. P4, P16, and P26. The Rossi et al. (2014) time series for Fukushima $^{137}Cs$ slightly lags the measured values at the ocean interior location at Stn. P26, but is in good agreement with the time series at the shelf-edge station, P4. The model predicts that the Fukushima $^{137}Cs$ signal will attain maximum values along line P during 2015–2016 and will then decline to <2 Bq/m$^3$ by 2020.

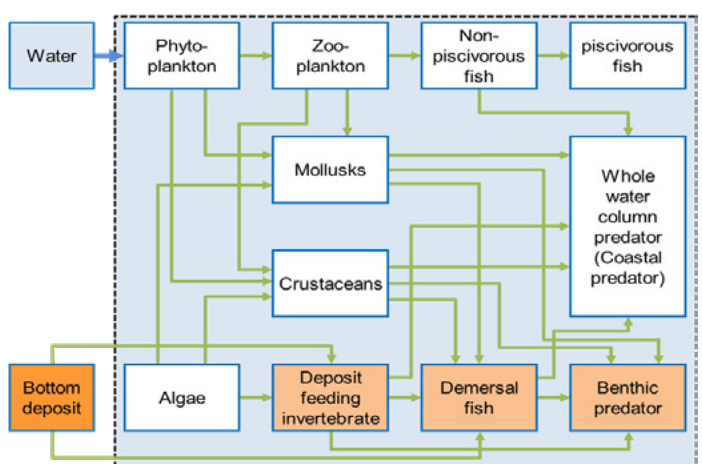
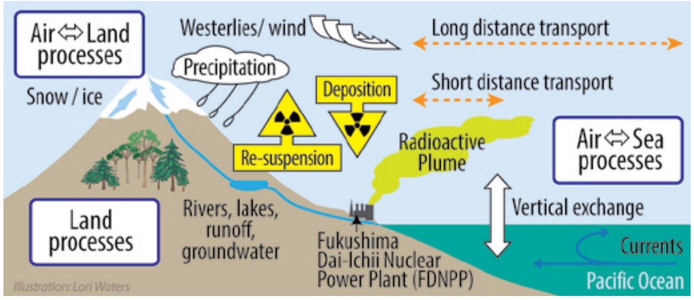



Figure 6. Marine food webs for the prediction of radionuclide transfer to marine species in BURN-POSEIDON model.

## Results

The results of WG 30 indicate that radioactivity levels in the North Pacific Ocean are presently declining in the marine ecosystem. However, rivers and ground water continue to add radioactivity to the ocean from the FDNPP site and from terrestrial regions in which accident-derived radioactivity has been temporarily sequestered.




## PICES WG 30 Recommendations

1. **Post-FDNPP monitoring of radionuclides ($^{134}$Cs, $^{137}$Cs) should be continued in the North Pacific for seawater and biota until levels have reached pre-2011 baseline fallout levels.**

   The complex hydrodynamic current regime of the western North Pacific has resulted in the injection of much of the FDNPP accident radioactivity inventory into Subtropical Mode Water (STMW) and Central Mode Water (CMW) that are being dispersed southward and eastward by subsurface transport. It is important to track the marine dispersal patterns for this large quantity of radioactivity.

2. **Oceanographic surveillance should be maintained for the FDNPP radionuclide inventory in North Pacific waters both from environmental radiological and ocean tracer perspectives.**

   Existing radiological policy standards differ among the PICES member countries, especially with regard to the long-term environmental and health effects of low-level radioactive wastes released into the marine environment.

   With the anticipated continued development of the nuclear power industry in the North Pacific, the effects of radioactivity releases on fisheries and the marine ecosystem may become an important environmental issue.

3. **Collaboration should be continued to examine the influence of long-term, low-level radioactive waste releases from coastal nuclear facilities on fisheries and marine ecosystems.**

   Canada's InFORM program enlisted citizen scientists to collect environmental samples that were analysed for radioactivity through government funding, and the results were posted to public websites. Direct engagement in the environmental monitoring was effective public outreach which helped to diminish the spread of false information regarding environmental threats.

4. **Public outreach and education aspects of environmental monitoring for radioactivity can be made significantly more effective if efforts are made to directly engage the public in some aspect of the surveillance operations.**

## WG 30 Membership

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WG 30's Second meeting, Yeosu, Korea, Oct. 2014. Front, L-R: Wen Yu, John Smith, Kathryn Higley, Yusheng Zhang, Kyung Tae Jung, Tao Yu, Daeji Kim; Back, L-R: Delvan Neville, He Wu, Tomowo Watanabe, In-Seong Han, Jung Hyup Lee, Seokwon Choi.

**For more information about PICES WG 30, please visit:**
**https://meetings.pices.int/members/working-groups/disbanded/wg30**