



RESEARCH LETTER

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Key Points:

- Wind anomaly reduced nutrient transport toward subtropics
- Chlorophyll in transition zone decreased to lowest levels yet observed
- Impacts may be felt in fish and top predator communities

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Anomalous winter winds decrease 2014 transition zone productivity in the NE Pacific

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Abstract Wind-driven transport from the North Pacific in winter provides nutrients to a highly productive region in the transition zone between the subarctic and subtropics. This region supports many species of fish, marine mammals, and seabirds. In winter 2013/2014, anomalous winds from the south weakened nutrient transport in the eastern North Pacific, resulting in substantial decreases in phytoplankton biomass. By January 2014, waters were warmer than usual by 3.5°C at the center of an affected area covering $\sim 1.5 \times 10^6$ km². South of this area, winter chlorophyll levels dropped to the lowest levels seen since the Sea-viewing Wide Field-of-view Sensor satellite began taking measurements in 1997. It is anticipated that impacts will be felt in some fisheries and among migrating predators this coming year.

1. Introduction

The nutrient-rich subarctic Pacific exports waters northward to the Arctic Ocean and southward to the subtropical Pacific, greatly enhancing productivity in these areas [Whitney *et al.*, 2013]. Prevailing westerly winds in winter drive the Ekman transport of surface waters southward [Ayers and Lozier, 2010], increasing primary productivity to at least 35°N in the eastern Pacific [Bograd *et al.*, 2004]. A chlorophyll front called the Transition Zone Chlorophyll Front (TZCF, the 0.2 mg m⁻³ chlorophyll contour between the subtropic (ST) and subarctic (SA)) is created that attracts predators such as albacore tuna, loggerhead turtles [Polovina *et al.*, 2001], other tuna, pinnipeds (elephant seals, sea lions, and fur seals), some albatross [Block *et al.*, 2011], flying squid, sharks, and a variety of fishes [Brodeur *et al.*, 1999].

In the winter of 2013/2014, extreme sea surface temperature (SST) anomalies were noticed starting in November and persisting through winter and spring (Figure 1a). The anomaly triggered this exploration of causes and effects. Online data and products provided information to show how atypical winds from the south blocked nutrient export from the SA to ST. As a result, surface chlorophyll in the transition zone (TZ) of the eastern Pacific was greatly diminished.

2. Data Sources

The backbone of this analysis are the SST and sea surface chlorophyll *a* data collected by Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (1997–2007) and Moderate Resolution Imaging Spectroradiometer (MODIS) (2002 to present) satellites. Giovanni (online data system, developed and maintained by the NASA Goddard Earth Sciences Data and Information Services Center, gdata1.sci.gsfc.nasa.gov) provides a simple avenue to both download data averaged over time and areas of interest and generate figures of chlorophyll *a* anomalies.

Columbia University's International Research Institute for Climate and Society (iridl.ldeo.columbia.edu) provides climate products mapping the wind and SST anomalies of this past winter based on data obtained from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR; NCEP-NCAR Reanalysis monthly zonal and meridional winds at standard pressure levels on a 2.5° latitudinal/longitudinal grid and Reynolds and Smith optimal interpolation sea surface temperature (OISST) version 2 monthly sea surface temperature anomalies on a 1.0° latitudinal/longitudinal grid; www.cpc.ncep.noaa.gov) [Kalnay *et al.*, 1996]. These SST data were also used to confirm the uniqueness of the warm anomaly of 2014 (<http://www.esrl.noaa.gov/psd/data/timeseries>).

3. Wind, SST, and Chlorophyll Anomalies

In October 2013, winter winds that are typically from the southwest in the NE Pacific transition zone (TZ) were blocked by a persistent flow from the south on the western edge of a high-pressure ridge (Figure 1a). This

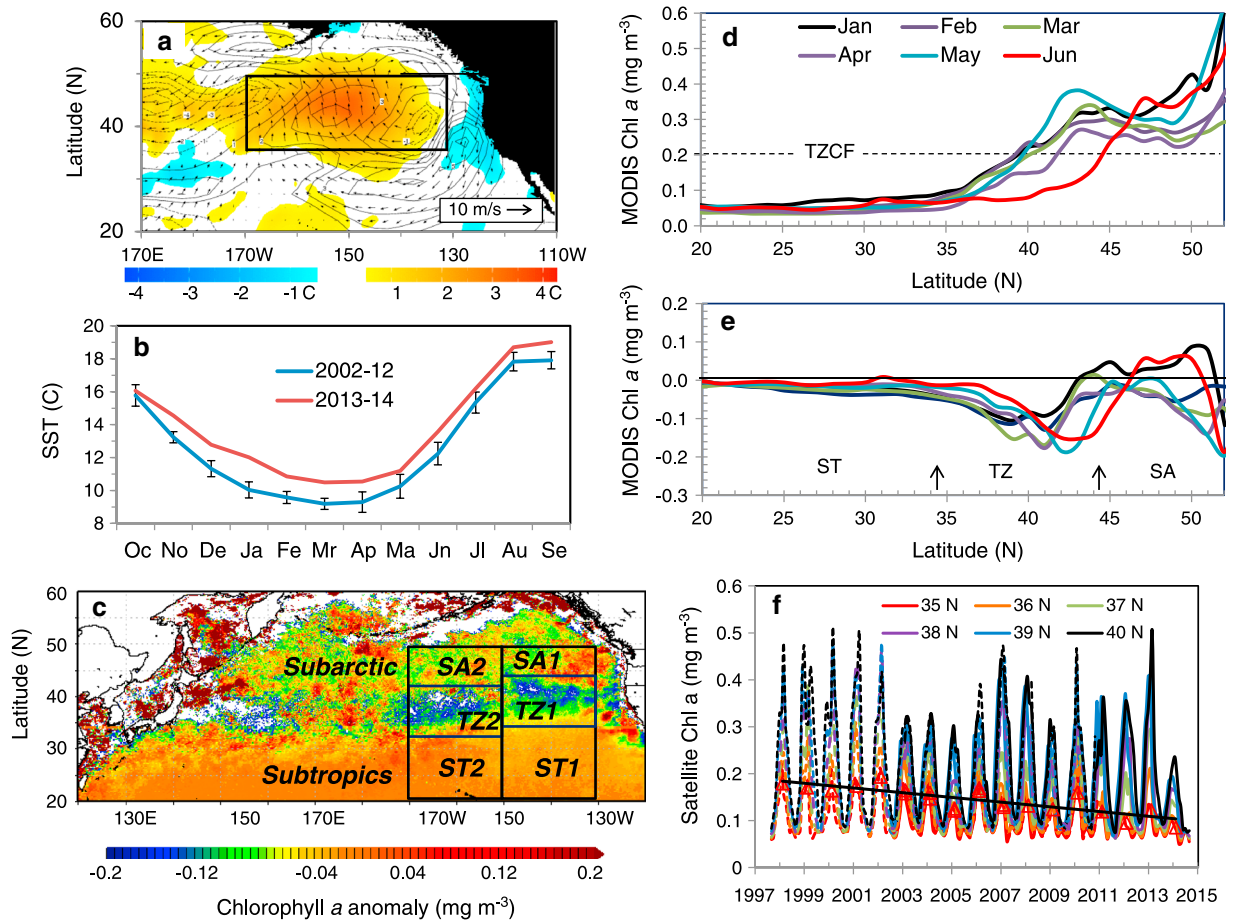


Figure 1. (a) December 2013 wind (1000 mbar, arrows) and SST anomalies (color scale, 1971–2000 base period) for the NE Pacific. Scales for wind (map inset) and SST (below map) are shown. The black rectangle delineates the region averaged in the following panel. (b) Monthly averaged sea surface temperatures (35–50°N, 130–170°W) for 2002–2012 (standard deviations shown as error bars) and October 2013 to September 2014. (c) Chlorophyll *a* anomaly for January–May 2014, over the subtropical and subarctic North Pacific. White regions over the ocean tend to be biased due to a lack of chlorophyll data caused by steep sun angle, cloud, or ice cover. Boxes delineate regions in which chlorophyll anomalies are estimated in Table 1. (d) Average monthly chlorophyll *a* between 130 and 150°W, averaged from 2003 to 2013 for the months January to June. The TZCF is denoted with a dashed line. (e) Chlorophyll *a* anomaly for 2014, compared with the 2003–2013 average, for the same area shown in Figure 1d. (f) Chlorophyll *a* time series using SeaWiFS (dashed lines) and MODIS (solid lines) monthly averages at several latitudes in TZ1. Winter averages (January–March, Δ) for 35°N show a decrease of $0.005 \text{ mg chl m}^{-3} \text{ yr}^{-1}$ between 1998 and 2014 (solid black line, linear regression with $r^2 = 0.64$).

pattern continued through January 2014, resulting in the weakest October–January zonal winds seen in the NCEP record (averaging 1.6 m s^{-1} from the west, well below the 1948–2012 average of $4.5 \pm 1.3 \text{ m s}^{-1}$ over the area 45–50°N, 140–150°W). The southerly component was stronger (4.7 m s^{-1}) than average ($2.9 \pm 1.5 \text{ m s}^{-1}$). Consequently, surface waters cooled less through fall and winter, creating a large pool of warm water ($\sim 1.5 \times 10^6 \text{ km}^2$) in the eastern SA and TZ regions. Near the center of this mass (41–45°N, 145–150°W), the temperature anomaly in January reached 3.5°C and was $>1.5^\circ\text{C}$ above any preceding year on record (1948–2014). The warm pool has persisted through the summer of 2014 (Figure 1b).

Since winter winds are responsible for most of the nutrient supply to the TZ [Ayers and Lozier, 2010], satellite data were used to assess impacts on winter chlorophyll *a* in the area affected by the wind and SST anomalies. A region of low chlorophyll starting in January and persisting through June in the eastern Pacific TZ is clearly identifiable in plots of chlorophyll *a* anomalies (Figure 1c). Thus, the focus of this analysis is on waters within and adjacent to the TZ.

Between 130 and 150°W, monthly average chlorophyll *a* (2003–2013) delineate a ST region of low phytoplankton biomass (avg = 0.066 mg m^{-3}), a TZ showing peak values of $0.33\text{--}0.39 \text{ mg m}^{-3}$ that migrate northward as winter progresses into spring, and a SA region with consistent values (0.30 mg m^{-3}) from

Table 1. Monthly/6 Month Chlorophyll *a* Averages and 2014 Anomalies for Regions Shown in Figure 1c^a

Region	Jan	Feb	Mar	Apr	May	Jun	Average
<i>2003–2013 Average Chlorophyll (mg m⁻³), 130–150°W</i>							
ST1	0.085	0.080	0.064	0.053	0.053	0.061	0.066
TZ1	0.265	0.282	0.282	0.235	0.216	0.171	0.242
SA1	0.308	0.312	0.313	0.296	0.317	0.300	0.308
<i>2014 Chlorophyll Anomaly (%), 130–150°W</i>							
ST1	–21	–36	–37	–23	–26	–9	–25
TZ1	–23	–30	–31	–35	–41	–38	–33
SA1	14	–11	–14	–18	–9	0	–6
<i>2003–2013 Average Chlorophyll (mg m⁻³), 150–170°W</i>							
ST2	0.105	0.110	0.097	0.070	0.062	0.058	0.084
TZ2	0.293	0.320	0.352	0.286	0.321	0.261	0.306
SA2	0.299	0.326	0.308	0.286	0.324	0.289	0.305
<i>2014 Chlorophyll Anomaly (%), 150–170°W</i>							
ST2	–18	–11	+3	–23	–17	–12	–13
TZ2	–18	–25	–44	–35	–28	–27	–30
SA2	–5	–17	–18	–17	–27	–8	–15

^aTZ1: 35 to 44°N, TZ2: 33 to 42°N.

January to June (Figure 1d). The 150–170°W region follows the same pattern, with the TZ being found slightly farther south (TZ1: 35 to 44°N, TZ2: 33 to 42°N; Table 1). Because coastal productivity is influenced by a variety of processes separate from those controlling open ocean (e.g., tidal mixing, continental iron sources, and timing of spring blooms), impacts of the warm anomaly on SA chlorophyll is truncated at 50°N.

Chlorophyll averages of 2003–2013 are used to compute anomalies in 2014. The loss of chlorophyll from the TZ is persistent and follows the seasonal progression of the TZCF (Figure 1e). This front is the most productive oceanic region during winter in the NE Pacific (Figure 1d) [Howard *et al.*, 2010], so a decline of 0.1 to 0.2 mg m⁻³ must have a substantial impact on energy transfer to higher trophic levels. Chlorophyll decreased by an average of 35% in TZ1 and 26% in TZ2 in the 6 months of winter and spring, 2014 (Table 1). Reduced levels of chlorophyll were also seen in subtropical waters most months, with losses averaging 0.015 and 0.008 mg m⁻³ in ST1 and ST2. Lower chlorophyll levels in the SA are likely caused by enhanced thermal stratification which weakens nutrient supply to the mixed layer [Whitney *et al.*, 1998].

Typically, the TZ1 chlorophyll front is centered at ~36°N in February [Bograd *et al.*, 2004] (Figure 1d). In 2014, the front sat near 39°N (Figure 1f), a northward displacement of ~300 km. In modeling impacts of global warming on NE Pacific productivity, Polovina *et al.* [2011] estimate a 1000 km northward shift in the TZCF over the next century. When fisheries and other ecosystem data are assessed, the warm anomaly of 2014 should provide insights into the issues facing marine ecosystems and fisheries as our oceans warm.

4. Part of a Longer-Term Trend

An expansion of the low-chlorophyll subtropical region in our oceans has been previously observed using SeaWiFS data [Polovina *et al.*, 2008]. One of the areas most impacted in their 9 year analysis period was the NE Pacific. By extending the time series with an additional 8 years with MODIS data, negative trends in chlorophyll *a* (0.035 to 0.06 mg m⁻³ yr⁻¹, $r^2 > 0.5$ for each linear regression) are found in the southern portion of transition waters between 33 and 36°N in TZ1 (Figure 1f). South of 33°N and north of 36°N, trends are small and nonsignificant. As extreme as the 2014 anomaly was, it appears to be part of a trend toward lower ocean productivity in the TZ of the NE Pacific. Further analyses are needed to understand why wind patterns are changing, although it has been suggested that winter winds across the North Pacific are affected by decreasing summer Arctic sea ice cover (increasing heat fluxes between ocean and atmosphere in late summer) [Jaiser *et al.*, 2012]. Atmospheric teleconnections between the Southern and Northern Hemispheres also strongly influence surface winds in the NE Pacific [Schwing *et al.*, 2010].

5. Possible Consequences

Both loss of phytoplankton biomass and northward displacement of productive frontal regions can cause a wide variety of impacts on higher trophic levels. Modeling theorizes substantial displacements of fishes and top predators toward the poles over the next century as subtropical waters warm and become less productive [Cheung *et al.*, 2009; Polovina *et al.*, 2011; Hazen *et al.*, 2013]. Also, the size of various fishes will likely decline due to increasing water temperature and reduced oxygen levels [Cheung *et al.*, 2013]. These impacts are often correlated with reduced nutrient supply to the surface ocean, brought about by enhanced thermal stratification. Changes in wind field also influence horizontal nutrient transport, with impacts being especially intense in frontal regions such as the TZ of the North Pacific.

Both the decreased size of fishes and their displacement away from the subtropics may disrupt feeding patterns, migration routes, and breeding strategies of a wide variety of organisms reliant on the TZCF for winter sustenance. The tuna and pinnipeds depending on TZCF productivity as they migrate across the Pacific [Block *et al.*, 2011] might feed poorly for half their journey (~3500 km between 130 and 170°W), search out a more productive region 300 km to the north, or not migrate. Each of these options would impact their nutrition and possibly their breeding options. Conversely, displacing the TZCF northward could benefit cool water fish such as salmon by providing them better winter feed.

Predictive models demonstrate that changing wind fields and ocean stratification are keys in assessing how climate will impact ocean productivity. Still, surprises await until we better resolve how remote forcings such as ice cover might cause shifts in wind fields and, consequently, the distribution of marine biomass.

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References

- Ayers, J. M., and M. S. Lozier (2010), Physical controls on the seasonal migration of the North Pacific transition zone chlorophyll front, *J. Geophys. Res.*, *115*, C05001, doi:10.1029/2009JC005596.
- Block, B. A., et al. (2011), Tracking apex marine predator movements in a dynamic ocean, *Nature*, *475*, 86–90, doi:10.1038/nature10082.
- Bograd, S. J., D. G. Foley, F. B. Schwing, C. Wilson, R. M. Laurs, J. J. Polovina, E. A. Howell, and R. E. Brainard (2004), On the seasonal and interannual migrations of the transition zone chlorophyll front, *Geophys. Res. Lett.*, *31*, L17204, doi:10.1029/2004GL020637.
- Brodeur, R., S. McKinnell, K. Nagasawa, W. Pearcy, V. Radchenko, and S. Takagi (1999), Epipelagic nekton of the North Pacific Subarctic and Transition Zones, *Progr. Oceanogr.*, *43*, 365–397.
- Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, and D. Pauly (2009), Projecting global marine biodiversity impacts under climate change scenarios, *Fish Fish.*, *10*, 235–251, doi:10.1111/j.1467-2979.2008.00315.x.
- Cheung, W. W. L., J. L. Sarmiento, J. Dunne, T. T. Frolicher, V. Lam, M. L. Deng Palomares, R. Watson, and D. Pauly (2013), Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems, *Nat. Clim. Change*, *3*, 254–258, doi:10.1038/nclimate1691.
- Hazen, E. L., et al. (2013), Predicted habitat shifts of Pacific top predators in a changing climate, *Nat. Clim. Change*, *3*, 234–238, doi:10.1038/nclimate1686.
- Howard, E., S. Emerson, S. Bushinsky, and C. Stump (2010), The role of net community production in air–sea carbon fluxes at the North Pacific subarctic–subtropical boundary region, *Limnol. Oceanogr.*, *55*(6), 2585–2596, doi:10.4319/lo.2010.55.6.2585.
- Jaiser, R., K. Dethloff, D. Handorf, A. Rinke, and J. Cohen (2012), Impact of sea ice cover changes on the Northern Hemisphere atmospheric winter circulation, *Tellus A*, *64*, 11,595, doi:10.3402/tellusa.v64i0.11595.
- Kalnay, E., et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471.
- Polovina, J. J., E. Howell, D. R. Kobayashi, and M. P. Seki (2001), The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources, *Progr. Oceanogr.*, *49*, 469–483.
- Polovina, J. J., E. A. Howell, and M. Abecassis (2008), Ocean's least productive waters are expanding, *Geophys. Res. Lett.*, *35*, L03618, doi:10.1029/2007GL031745.
- Polovina, J. J., J. P. Dunne, P. A. Woodworth, and E. A. Howell (2011), Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming, *ICES J. Mar. Sci.*, *68*, 986–995, doi:10.1093/icesjms/fsq198.
- Schwing, F. B., R. Mendelssohn, S. J. Bograd, J. E. Overland, et al. (2010), Climate change, teleconnection patterns, and regional processes forcing marine populations in the Pacific, *J. Mar. Syst.*, *79*, 245–257, doi:10.1016/j.jmarsys.2008.11.027.
- Whitney, F. A., C. S. Wong, and P. W. Boyd (1998), Interannual variability in nitrate supply to surface waters of the northeast Pacific Ocean, *Mar. Ecol. Prog. Ser.*, *170*, 15–23.
- Whitney, F. A., S. J. Bograd, and T. Ono (2013), Nutrient enrichment of the subarctic Pacific Ocean pycnocline, *Geophys. Res. Lett.*, *40*, 1–6, doi:10.1002/grl.50439.