Impact of the “Godzilla El Niño” Event of 2015–2016 on Sea-Surface Temperature and Chlorophyll-*a* in the Southern Gulf of California, Mexico, as Evidenced by Satellite and In Situ Data

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Impact of the "Godzilla El Niño" Event of 2015–2016 on Sea-Surface Temperature and Chlorophyll-*a* in the Southern Gulf of California, Mexico, as Evidenced by Satellite and In Situ Data[1]

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Abstract: During 2015–2016, a strong El Niño event, nicknamed the "Godzilla El Niño," occurred in the Pacific Ocean. Using satellite imagery, in this article we assess impacts of this event on sea-surface temperature and chlorophyll-*a* concentrations in the southern Gulf of California. Daily images of sea-surface temperatures and chlorophyll-*a* were obtained by satellite from the Moderate Resolution Imaging Spectroradiometer for the period from January 2013 to December 2017. A circular area ≈ 46.8 km in diameter in the central part of the gulf was selected to evaluate monthly variation of both parameters. Hydrographic data generated during a research cruise in November 2016 were used to evaluate water mass distributions. Results revealed strong seasonal variability, with high chlorophyll-*a* concentrations recorded during winter and low values during summer. Contrary to predictions, the "Godzilla El Niño" event apparently did not have as large an impact on the phytoplankton biomass, expressed as chlorophyll-*a*, in this region in comparison to other areas and to previous strong El Niño events. This is likely related to gulf dynamics and to the mechanism of productivity enhancement, although further observations are required to confirm this theory. Results presented contribute to a better understanding of the highly productive and unique Gulf of California ecosystem.

Keywords: Godzilla El Niño, chlorophyll-*a*, sea-surface temperature, Gulf of California

The Gulf of California is a unique and highly productive ecosystem that contains immense biodiversity, including endemic, endangered, threatened, and protected species. The gulf is not only considered to be one of the most important marine biodiversity hot spots in the world (Lluch-Cota et al. 2007, Páez-Osuna et al. 2017) but is also the most important fishing region in Mexico, supporting fisheries with species of high commercial value, such as shrimp, squid, tuna, and sardines, which together make up more than 60% of the country's annual catch (Arreguín-Sánchez et al. 2017). The Gulf of California is an enclosed sea delimited by the peninsula of Baja California to the west and by the coasts of Sonora and Sinaloa to the east. It extends from 23° N to 32° N and is 1,200 km long,

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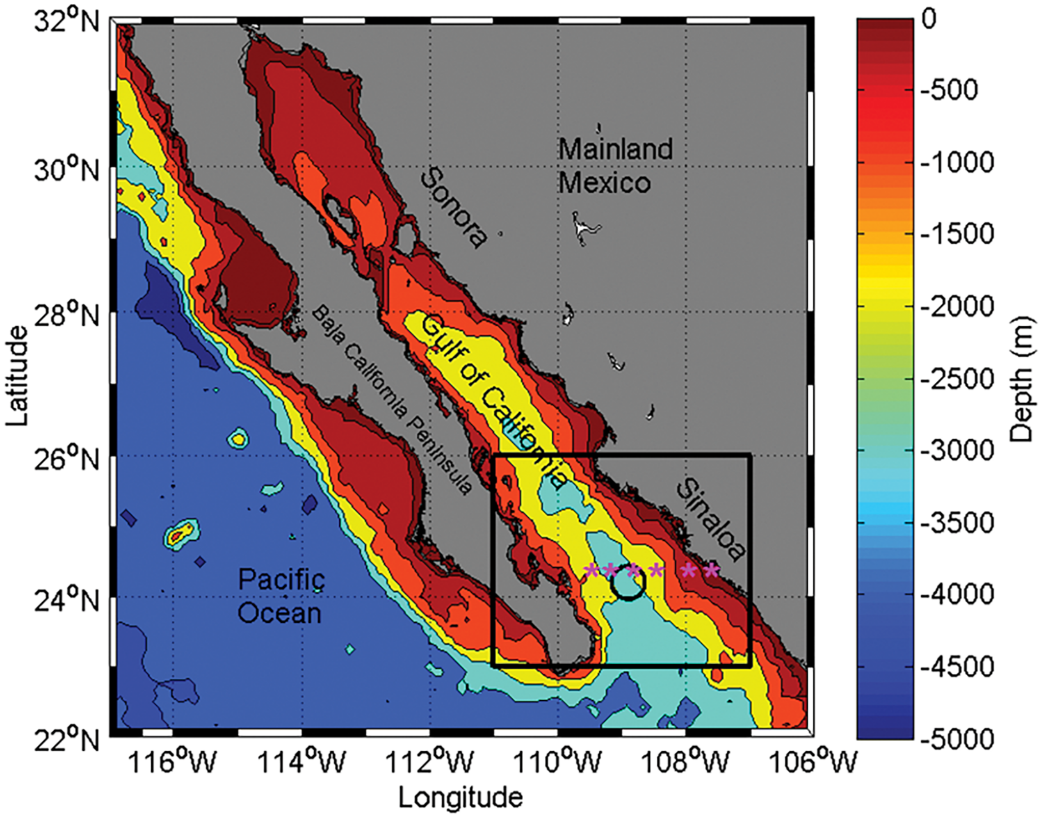

Figure 1. Gulf of California, bathymetry in meters. The rectangle represents the area of interest. The black circle is ≈46.8 km in diameter and centered at 24.21° N, 109.00° W. The * symbols indicate locations of the six hydrographic stations situated along the connection with the Pacific Ocean.

and its width varies from 108 to 234 km. The gulf encompasses 40 coastal lagoons and 922 islands and islets (Páez-Osuna et al. 2017). The topography of the gulf is complex: its northern part is shallow, with a maximum depth of approximately 200 m; its southern part has depths varying from 2,000 to 3,200 m; and the gulf includes strong bathymetric gradients (Salas de León et al. 2011) (Figure 1).

Due to the gulf's connection with the Pacific Ocean, almost all major marine events that occur in the latter can also be observed in the gulf itself, making the area an extraordinary laboratory in which to study marine dynamics and processes (Páez-Osuna et al. 2017). One of these events is the El Niño/Southern Oscillation (ENSO). Not only do ENSO events represent one of the major drivers of interannual global ocean-atmospheric climate variability, they have also been shown to affect biological productivity and sinking particle fluxes (Park et al. 2011, Wolter and Timlin 2011). In 2015, one of the strongest ENSO events on record was forecast by the National Oceanic and Atmospheric Administration (NOAA) to intensify during the winter of 2015–2016 (Klein 2015, Whitney 2015, Stramma et al. 2016). This event was nicknamed the "Godzilla El Niño" (Schiermeier 2015) and surpassed the intensities of the two previous very strong ENSO years of 1982–1983 and 1997–1998; the latter is also referred to as "the climate event of the twentieth century" (Changnon 2000). Both previous events were associated with significant effects on the marine life in the Gulf of California. During the 1982–1983 event, the habitual distribution of silicoflagellates was modified by the incursion of tropical warm surface waters into the gulf, occurring mainly along the continental margin of Mexico, which resulted in the absence of and/or decrease in some species (Pérez-Cruz and Molina-Cruz 1988).

During the 1997–1998 event, the increase in sea-surface temperature (SST) (>4°C) and the stratification of the water column resulted in a sinking of the thermocline and the 15°C and 18°C isotherms, both of which affected marine organisms (Obeso-Nieblas et al. 2004). For example, a drastic decrease in the *Sardinops caeruleus* fishery was documented, with the spawning environment of commercial species also being impacted (Sánchez-Velasco et al. 2002).

A number of consequences of the recent "Godzilla El Niño" event have already been documented. During this event, the warmest water and strongest convection were reported as being hundreds of kilometers farther west along the equator than those of previous events (Kintisch 2016). Two strong anomalies were documented in the eastern North Pacific: anomalous southerly winds, which weakened nutrient transport and resulted in substantial decreases in phytoplankton biomass, and a 3.5°C increase in water temperature by January 2014 (Whitney 2015). Similarly, Stramma et al. (2016) reported a clear temperature increase that led to lower densities and lower nutrient concentrations in the upper 350 m at the equator. The effects in the southern Gulf of California were evaluated by Sánchez-Velasco et al. (2017), who reported no dramatic changes in the total fish larvae abundance during this warm event. Indeed, larval abundance was unexpectedly high, reflecting the possible adaptability of tropical species to prolonged periods of oceanic warming.

Our aim in this paper is to assess the impact of the "Godzilla El Niño" 2015–2016 event on the SST and surface chlorophyll-*a* concentrations in the southern Gulf of California, as evidenced by hydrographic and satellite observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) covering the period from January 2013 to December 2017. Because a great proportion of sea-surface chlorophyll-*a* variation occurs at small scales, it is sufficiently stable to be tracked by satellite observations for months, even if the chlorophyll at the sea surface is not a conservative tracer (Mahadevan 2002, Ciappa 2009). The selected time period is also likely to be representative of the variability in the surface waters of the Gulf of California before, during, and after the event. In addition, we assume that lower trophic levels support the extraordinary biological productivity of the area.

MATERIALS AND METHODS

To characterize ENSO phenomena, we obtained Multivariate ENSO Index (MEI) data from the NOAA Earth System Research Laboratory (https://www.esrl.noaa.gov/psd/enso/mei/) for the period from January 2013 to December 2017. The MEI is derived from multiple meteorological and oceanographic parameters (e.g., sea-level pressure, the zonal and meridional components of the sea-surface wind, the sea-surface temperature, surface air temperature, and total cloudiness fraction of the sky) over the tropical Pacific and has been shown to reflect the nature of the coupled ocean-atmosphere system better than other indices (Wolter and Timlin 2011). Large positive MEI values indicate the occurrence of El Niño conditions, and large negative values indicate the occurrence of La Niña conditions.

A location in the middle of the Gulf of California (24.21° N, 109.00° W) was selected to analyze temporal evolution of the 2015–2016 El Niño event, averaged over a circular area ≈ 46.8 km in diameter (black circle in Figure 1). Satellite snapshot images of SST and chlorophyll-*a* concentration were obtained from MODIS-AQUA for 1 day of each month during the period from January 2013 to December 2017. The images, with spatial resolutions of 3.5 km (Local Area Cover), were processed at Level 1 and Level 2 (http://oceancolor.gsfc.nasa.gov) using SeaDAS version 7.4 and standard algorithms to analyze the patterns among both variables. A time-series analysis was conducted by a loess regression smoothing (0.2) in plotyy function for Matlab (Mathworks, Inc. 2011).

To characterize the water mass distribution in the domain of interest, we used hydrographic data generated at six stations across the entrance to the Gulf of California (Figure 1). The data were collected in November 2016 during the oceanographic cruise "Paleomar-II" on board the RV *El Puma* from the National Autonomous University of Mexico. A Seabird (SBE-19) CTD was used to measure conductivity, temperature, and depth, with conservative temperature (Θ, °C), absolute salinity (S_A, g kg^{-1}), and density anomalies ($\sigma\Theta$, kg m^{-3}) calculated via the Thermodynamic Equation of Seawater-2010 (TEOS-10) (McDougall and Barker 2011). Finally, a temperature-salinity (T-S) diagram was constructed using the functions available in the Gibbs Seawater Oceanographic Toolbox (McDougall and Barker 2011).

RESULTS

Satellite observations from MODIS-AQUA during the study period revealed clear environmental differences and strong seasonal variabilities. Although our data time series includes the period from 2013 to 2017, we only present images for the period when the "Godzilla El Niño" occurred (2014–2016). The rest of the series was used to characterize the conditions before that event. The MEI during the period analyzed showed positive values reaching their maxima (>2.2) during the winter of 2015–2016, preceded by a negative phase (Figure 2, *top*). The variability in both SST and chlorophyll-*a* at the study location exhibited a common trend: as tempera-

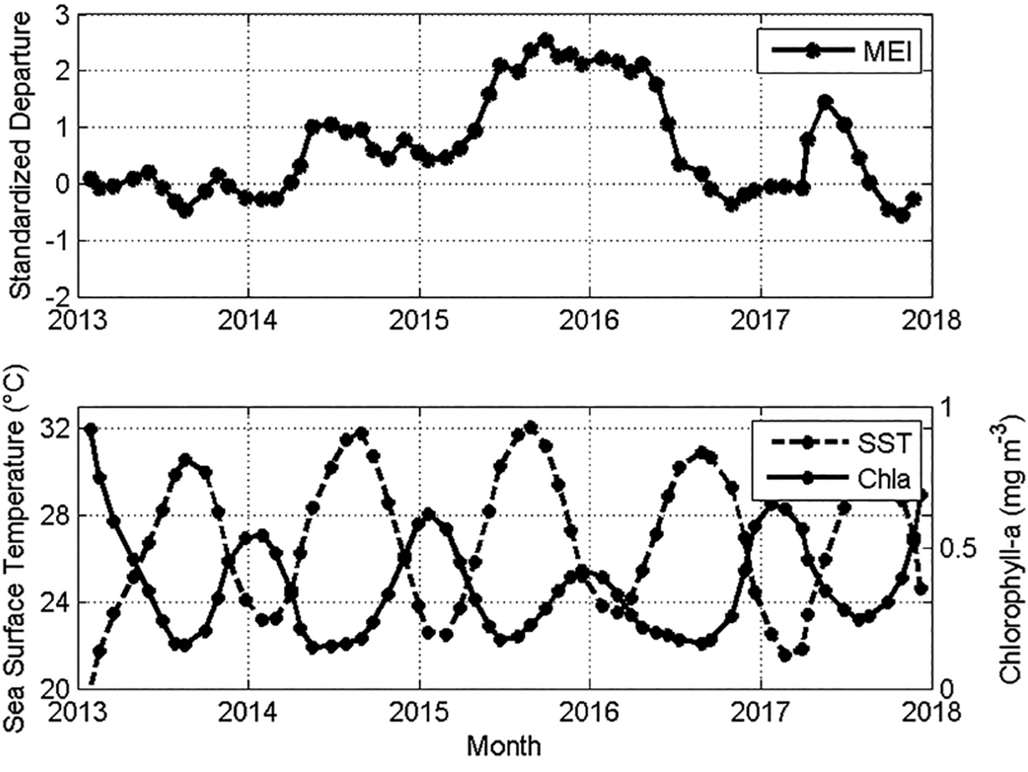

FIGURE 2. (*Top*) Multivariate ENSO Index (MEI) for the period from January 2013 to December 2017, and (*bottom*) time series of sea-surface temperature (SST) (°C) and chlorophyll-*a* (Chla) concentrations (mg m^{-3}) at a fixed position (24.21° N, 109.00° W) averaged for a circular area ≈ 46.8 km in diameter.

ture decreased during the winter, chlorophyll-*a* concentrations increased, and during the summer, when SST were at their highest, the chlorophyll-*a* concentration reached its minimum (Figure 2, *bottom*). Correlation analysis performed to support this observation revealed an inverse (R = –0.70) and statistically significant relationship ($P = .00001$) between the two parameters.

During 2014, before the “Godzilla El Niño” event, SST values ranged from 22.3°C to 33.1°C, with the lowest values recorded during January and the highest from July to September. Chlorophyll-*a* concentrations ranged from 0.13 to 0.86 mg m^{-3}, with the highest values observed during winter and the lowest during August (Figure 3). One common feature was the presence of filaments or

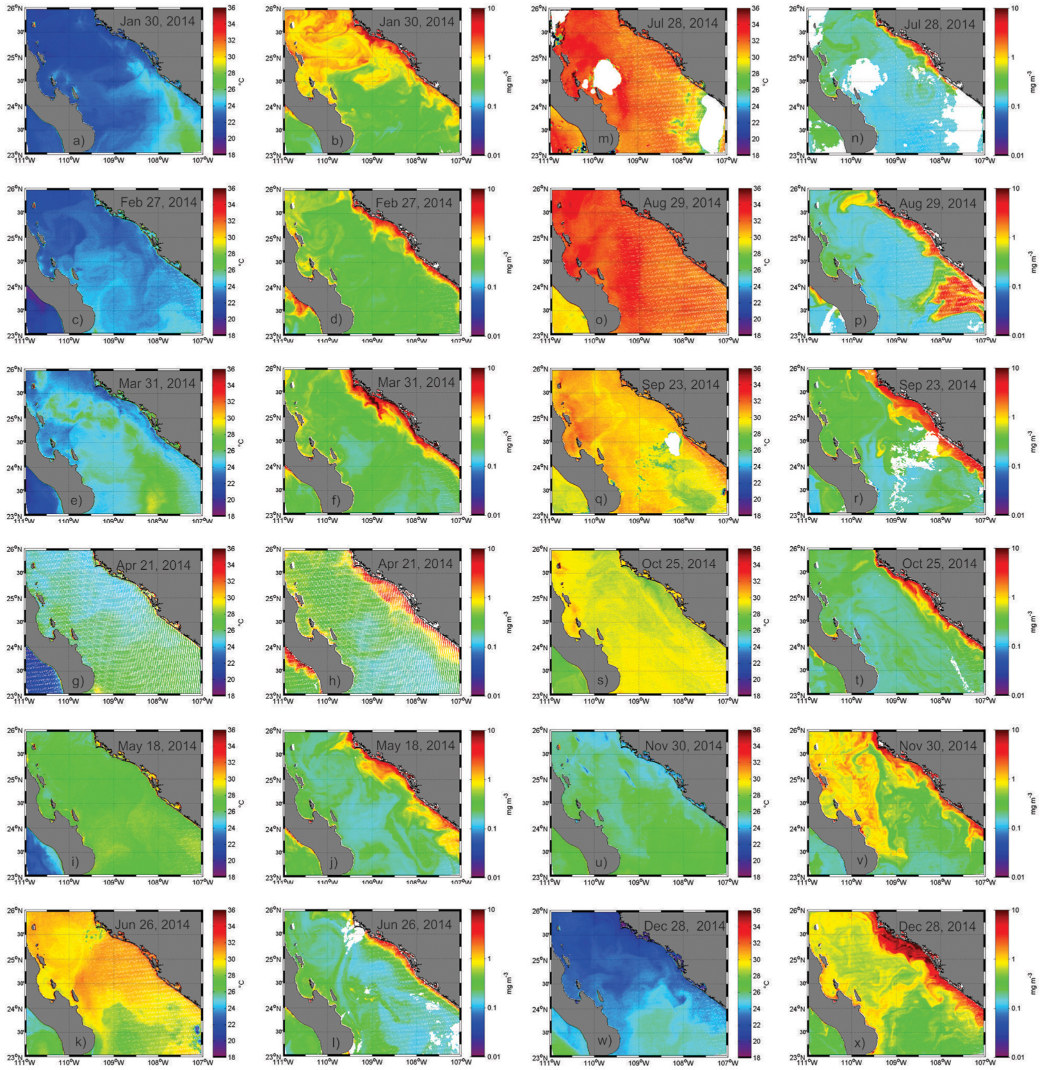

FIGURE 3. Satellite snapshot images of SST (°C) and chlorophyll-*a* concentrations (mg m^{-3}) for 1 day cloud-free every month during 2014.

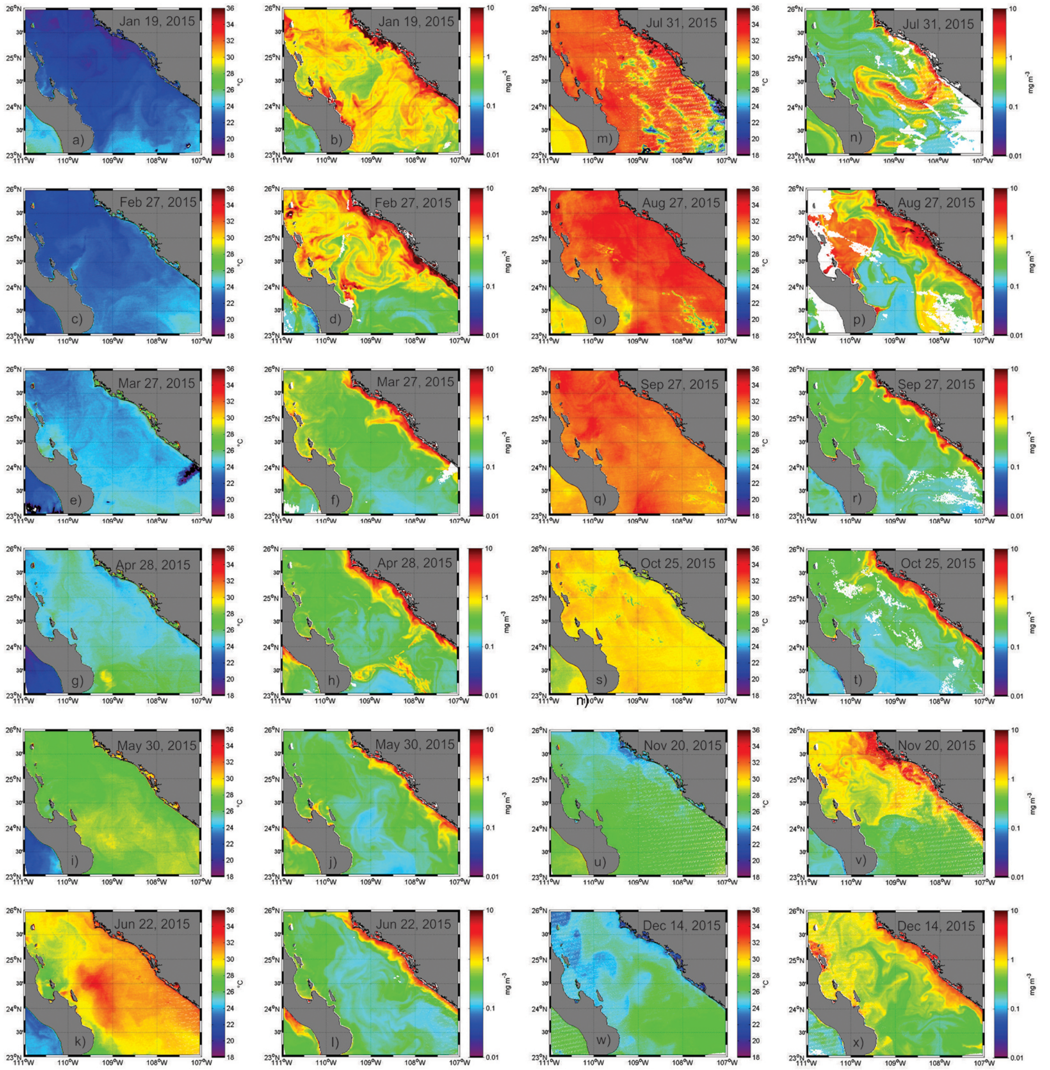

FIGURE 4. Satellite snapshot images of SST (°C) and chlorophyll-*a* concentrations (mg m^{-3}) for 1 day cloud-free every month during 2015.

layers of high chlorophyll content associated with mesoscale structures (features with radius scales on the order of 100 km) along the gulf.

During 2015, the SST values were slightly and unexpectedly lower than those of 2014, ranging from 21.4°C to 32.5°C, although the lowest temperatures were still recorded during the winter and the highest during the summer. The chlorophyll-*a* concentrations were slightly higher than those in 2014, ranging from 0.17 to 0.92 mg m^{-3}. Although the maximum values were again observed during the winter and the lowest during the summer, the winter data varied from those of 2014, with relatively low values of chlorophyll-*a* recorded (≈ 0.5 mg m^{-3}) (Figure 4). During 2016, the SST values again

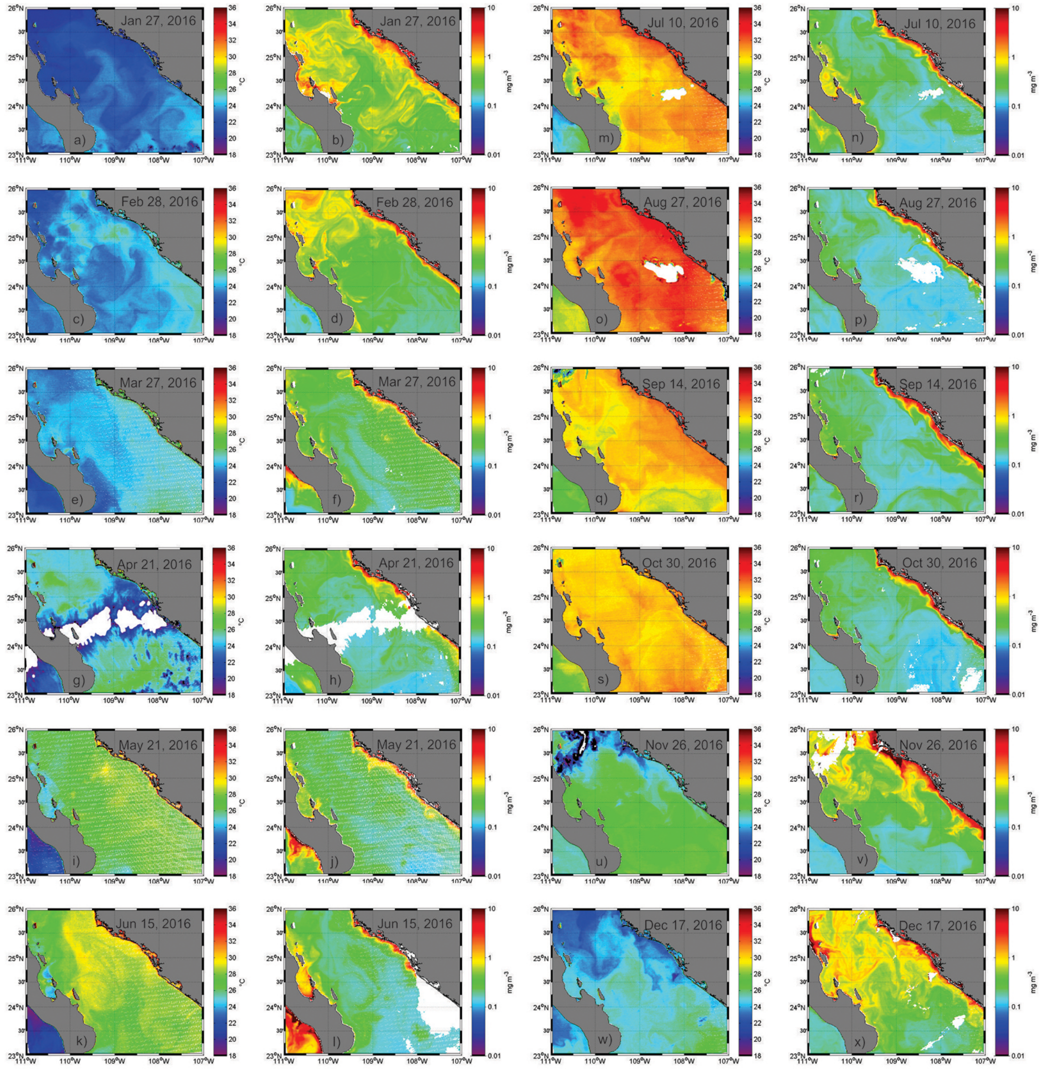

FIGURE 5. Satellite images of SST (°C) and chlorophyll-*a* concentrations (mg m^{-3}) for 1 day cloud-free every month during 2016.

decreased, ranging from 23°C to 31.8°C, and the chlorophyll-*a* concentrations also reached their lowest values of the 3-yr study period, ranging from 0.15 to 0.60 mg m^{-3} (Figure 5).

According to the water mass classification scheme for the Gulf of California proposed by Lavín et al. (2009), the T-S diagram obtained at the six hydrographic stations along the mouth of the Gulf of California during November 2016 shows the presence of six water masses: the Pacific Deep Water (PDW, $S > 34.5$ and $T < 4°C$), Pacific Intermediate Water (PIW, $34.5 < S < 34.8$ and $4°C < T < 9°C$), Subtropical Subsurface Water (StSsW, $34.5 < S < 35$ and $9 < T < 18°C$), a small part of the California Current Water (CCW, $S < 34.5$ and $12°C < T < 18°C$), the Tropical

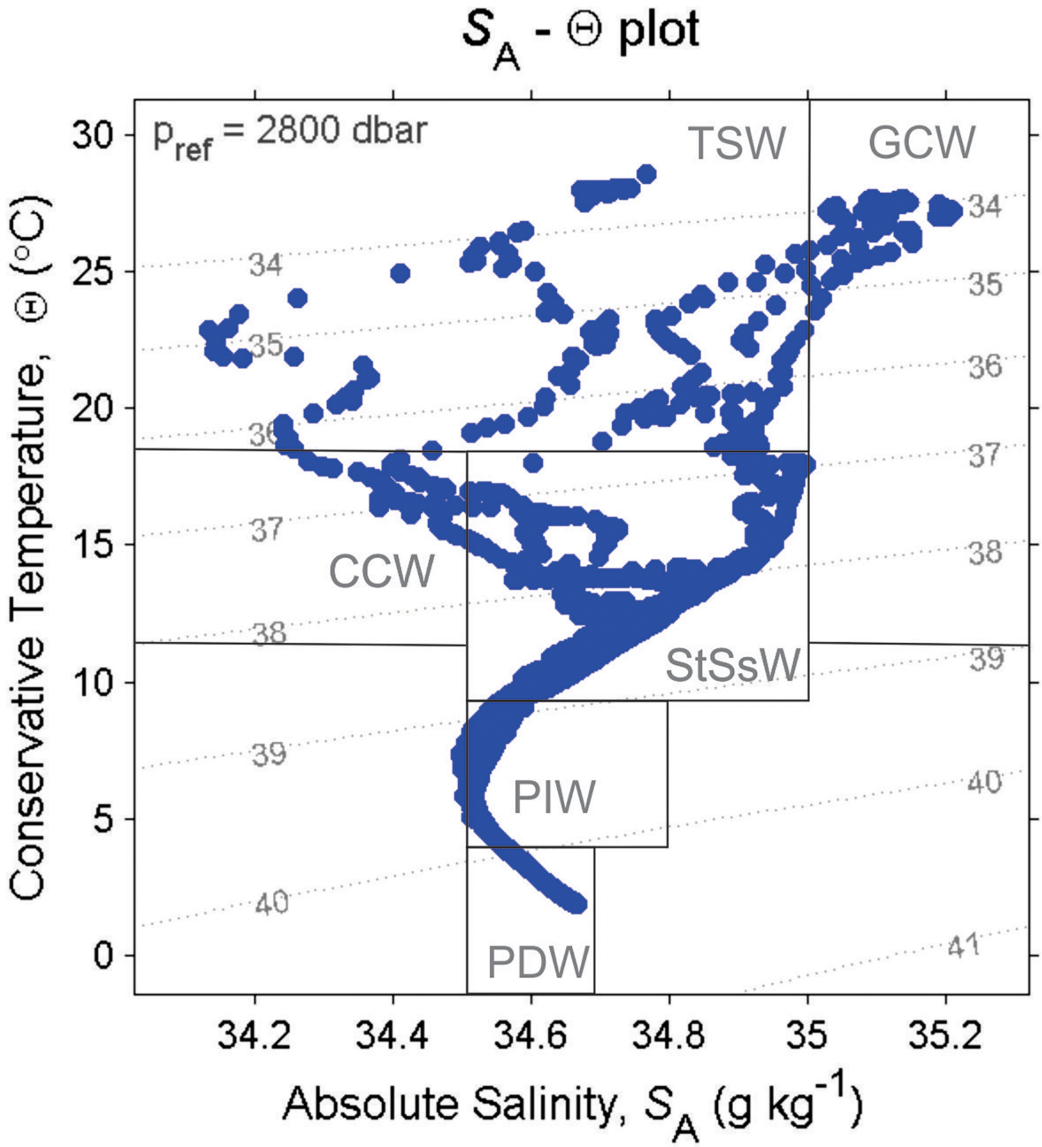

Figure 6. Conservative temperature (Θ) (°C) - Absolute Salinity (g kg^{-1}) diagram: Gulf of California Water (GCW), Tropical Surface Water (TSW), California Current Water (CCW), Subtropical Subsurface Water (StSsW), Pacific Intermediate Water (PIW), and Pacific Deep Water (PDW).

Surface Water (TSW, $S < 34.9$ and $T > 18°C$), and the Gulf of California Water (GCW, $S > 34.9$ and $T > 12°C$) (Figure 6). The greatest proportion of TSW and CCW occurred at the stations located in the middle of the gulf.

DISCUSSION

As a result of intensive research undertaken regarding the changes and processes associated with previous strong El Niño events, it is well documented that El Niño event dynamics modulate sea-surface temperature, salinity, density, the mixed layer, oxycline depth, nutrient levels, and chlorophyll-*a* concentrations (Chavez et al. 2002, Collins et al. 2010, Cai et al. 2015, Stramma et al. 2016). Even though the 2015–2016 ENSO was of a magnitude similar to those of the other two mega ENSOs, its reduced impact on the Gulf of California ecosystem was corroborated by satellite and in situ observations. Indeed, chlorophyll-*a* concentrations during February 2015 were relatively and unexpectedly higher (0.92 mg m^{-3}) than those of 2014, and no abrupt increase in SST was recorded (Figure 2, *bottom*). Similar observations were made by Sánchez-Velasco et al. (2017), who found no dramatic changes in the pelagic ecosystem, but instead documented a relatively high abundance of fish larvae during the 2015 event in the southern Gulf of California. The latter finding was likely due to a high tolerance to sustained warming of the tropical species with habitats in the Eastern Tropical Pacific. Santamaría del Angel et al. (1994) reported that the El Niño event of 1982 did not strongly alter the phytoplankton biomass recorded in the northern region of the gulf, because strong tidal mixing and upwelling greatly masked its effect. Some parts of the central and northern gulf exhibited either weak or no effects from El Niño (Álvarez-Borrego 2012); this could also be the case for our observations, because no direct effect was observed in the southern Gulf of California. The seasonal variability observed in the study reported here (Figure 2, *bottom*) is in agreement with that previously reported for the southern gulf as reflecting normal periods of surface-layer heating and cooling, which in turn determine the mixed layer and the availability of nutrients that promote high phytoplankton biomass (Álvarez-Borrego 2012).

In terms of water mass distribution, during those periods not affected by El Niño the Tropical Surface Water (TSW) and Subtropical Subsurface Water (StSsW) masses are not usually present in the southern Gulf of California. However, during El Niño episodes, their presence varies spatially (Obeso-Nieblas et al. 2004, Obeso-Nieblas et al. 2014), which may be the reason why both water masses were observed in the study reported here, particularly with the predominance of the TSW at the station located in the middle of the gulf. Similar observations were made during the El Niño event of 1997–1998, when the TSW filled the Gulf of California but was blocked on the Pacific side of the peninsula (Durazo and Baumgartner 2002). The presence of the Subtropical Subsurface Water (StSsW) in this study coincides with the findings of both Álvarez-Borrego and Schwartzlose (1979), who reported important incursions of this water mass during 1957 (an El Niño year), and Castro et al. (2000), who reported a significant signal at the mouth of the Gulf of California during the El Niño event of 1997–1998. Although the presence of the water masses observed here is in agreement with the data reported for previous El Niño events, their presence seems to have had no effect on the trophic state of the study area. This is the case despite the high temperature of the TSW and GCW, which could be associated with an oligotrophic regime. Indeed, Monreal-Gómez et al. (2001) documented the effects of different water masses on the trophic state of the region and identified the presence of the GCW in the southern Gulf of California. Those authors reported chlorophyll-*a* concentrations varying from 0.04 to 0.50 mg m^{-3}, a range that agrees with the values observed in the study reported here. Recently, Espinoza-Carreón and Escobedo-Urías (2017) showed the water mass distributions using in situ data from 1939 to 1993. Comparing their results with our Figure 6, it appears that major proportions of CCW and TSW are present; however, their results came from the stations located in the middle and northern areas of the gulf, where the CCW is practically nonexistent, and the presence of TSW in their T-S diagram could be strongly related to the ENSO events that occurred in the period of their analysis.

Several mechanisms associated with the dynamics of the gulf could be involved in the apparent nonimpact of the "Godzilla El Niño" event. The gulf is characterized by the presence of intense tides that are produced mainly by co-oscillation with those of the Pacific Ocean, which in turn generate hydrodynamic processes such as mesoscale cyclonic and anticyclonic eddies (Salas de León et al. 2011) as well as internal waves and fronts (Filonov and Lavín 2003). The interior of the gulf is associated with various fertilization mechanisms, including a water exchange with the Pacific Ocean, wind-induced upwelling, and tidal mixing (Álvarez-Borrego 2012), which increase chlorophyll concentrations that in turn favor zooplankton biomass. Vertical mixing from tidal vorticity dynamics can also induce significant upwelling in the gulf, which in turn produces elevated nutrient concentrations and enhanced phytoplankton production (Salas de León et al. 2011). Strong mixing processes have also been documented in the central and northern regions of the gulf, injecting cool nutrient-rich waters into the euphotic zone and supporting high biological production, thereby creating circumstances similar to those of constant upwelling (Álvarez-Borrego 2012). Additional mechanisms could be related to this noneffect in the Gulf of California. In particular, the MEI time series (Figure 2, *top*) shows that the "Godzilla El Niño" occurred after a negative phase, and the two previous mega ENSOs occurred after a prolonged positive phase, which would set the stage for different ecosystem responses, especially in the higher trophic level that has a longer response time.

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Literature Cited

Álvarez-Borrego, S. 2012. Phytoplankton biomass and production in the Gulf of California: A review. Bot. Mar. 55:119–128.

Álvarez-Borrego, S., and R. A. Schwartzlose. 1979. Masas de agua del Golfo de California. Cienc. Mar. 6:43–63.

Arreguín-Sánchez, F., P. del Monte-Luna, M. J. Zetina-Rejón, and O. Albañez-Lucero. 2017. The Gulf of California large marine ecosystem: Fisheries and other natural resources. Environ. Dev. 22:71–77 (http://dx.doi.org/10.1016/j.envdev.2017.03.002).

Cai, W., A. Santoso, G. Wang, S. W. Yeh, S. I. An, K. M. Cobb, M. Collins, E. Guilyardi, F. F. Jin, J. S. Kug, M. Lengaigne, M. J. McPhaden, K. Takahashi, A. Timmermann, G. Vecchi, M. Watanabe, and L. Wu. 2015. ENSO and a greenhouse warming. Nat. Clim. Change 5:849–859 (doi:10.1038/nclimate2743).

Castro, R., A. S. Mascarenhas, R. Durazo, and C. A. Collins. 2000. Seasonal variation of the temperature and salinity at the entrance to the Gulf of California, Mexico. Cienc. Mar. 26:561–583.

Changnon, S. A. 2000. El Niño 1997–1998: The climate event of the century. Oxford University Press, New York.

Chavez, F. P., J. T. Pennington, C. G. Castro, J. P. Ryan, R. P. Michisaki, B. Schlining, P. Walz, K. R. Buck, A. McFadyen, and C. A. Collins. 2002. Biological and chemical consequences of the 1997–1998 El Niño in central California waters. Prog. Oceanogr. 54:205–232.

Ciappa, A. C. 2009. Surface circulation patterns in the Sicily Channel and Ionian Sea as revealed by MODIS chlorophyll images from 2003 to 2007. Cont. Shelf Res. 29:2099–2109.

Collins, M., S. I. An, W. Cai, A. Ganachaud, E. Guilyardi, F. F. Jun, M. Jochum, M. Lengaigne, S. Power, A. Timmermann, G. Vecchi, and A. Wittenberg. 2010. The impact of global warming on the tropical Pacific Ocean and El Niño. Nat. Geosci. 3:391–397.

Durazo, R., and T. R. Baumgartner. 2002. Evolution of oceanographic conditions off Baja California: 1997–1998. Progr. Oceanogr. 54:7–31.

Espinoza-Carreón, T. L., and D. Escobedo-Urías. 2017. South region of the Gulf of California large marine ecosystem upwelling, fluxes of CO2 and nutrients. Environ. Dev. 22:42–51.

Filonov, A., and M. F. Lavín. 2003. Internal tides in the northern Gulf of California. J. Geophys. Res. 108 (C5): 3151 (doi:10.1029/2002JC001460).

Kintisch, E. 2016. How a 'Godzilla' El Niño shook up weather forecasts. Science (Washington, D.C.) 352:1501–1502 (doi:10.1126/science.352.6293.1501).

Klein, K. 2015. NOAA predicts strong El Niño. EOS, Trans. Am. Geophys. Union 96 (doi:10.1029/2015EO035535).

Lavín, M. F., R. Castro, E. Beier, V. M. Godínez, A. Amador, and P. Guest. 2009. SST, thermohaline structure, and circulation in the southern Gulf of California in June 2004 during the North American Monsoon Experiment. J. Geophys. Res. Oceans 114: C02025 (doi:10.1029/2008JC004896).

Lluch-Cota, S. E., E. A. Aragón-Noriega, F. Arreguín-Sánchez, D. Aurioles-Gamboa, J. J. Bautista-Romero, and R. C. Brusca. 2007. The Gulf of California: Review of ecosystem status and sustainability challenges. Progr. Oceanogr. 73:1–26.

Mahadevan, A. 2002. Biogeochemical patchiness at the sea surface. Geophys. Res. Lett. 29:321–324.

Mathworks, Inc. 2011. MATLAB. Global Optimization Toolbox: User's Guide (r2011b). (www.mathworks.com/help/pdf_doc/gads/gads_tb.pdf).

McDougall, T. J., and P. M. Barker. 2011. Getting started with TEOS 10 and the Gibbs Seawater (GSW) Oceanographic Toolbox. SCOR/IAPSO WG127.

Monreal-Gómez, M. A., A. Molina-Cruz, and D. A. Salas de León. 2001. Water masses and cyclonic circulation in Bay of La Paz, Gulf of California, during June 1998. J. Mar. Syst. 30:305–315.

Obeso-Nieblas, M., J. H. Gaviño-Rodríguez, H. Obeso-Huerta, and S. I. Muñoz-Casillas. 2014. Spatial termohaline variability, water masses and geostrophic circulation in Bahía de La Paz, Gulf of California. Rev. Biol. Mar. Oceanogr. 49:413–426 (doi:10.4067/S0718-19572014000300002).

Obeso-Nieblas, M., B. Shirasago, L. Sánchez-Velasco, and J. H. Gaviño-Rodriguez. 2004. Hydrographic variability in Bahía de La Paz, B.C.S, Mexico during the 1997–1998 El Niño. Deep-Sea Res. II 51:689–710.

Páez-Osuna, F., S. Álvarez-Borrego, A. C. Ruiz-Fernández, J. García-Hernández, M. E. Jara-Marini, M. E. Bergés-Tiznado, A. Piñón-Gimate, R. Alonso-Rodríguez, M. Soto-Jiménez, M. G. Frías-Espericueta, J. R. Ruelas-Inzunza, C. R. Green-Ruiz, C. C. Osuna-Martínez, and J. A. Sanchez-Cabeza. 2017. Environmental status of the Gulf of California: A pollution review. Earth-Sci. Rev. 166:181–205.

Park, J. Y., J. S. Kug, J. Park, S. W. Yeh, and C. J. Jang. 2011. Variability of chlorophyll associated with El Niño–Southern Oscillation and its possible biological feedback in the equatorial Pacific. J. Geophys. Res. 116: C10001 (doi:10.1029/2011JC007056).

Pérez-Cruz, L., and A. Molina-Cruz. 1988. El Niño 1983: Effect on the distribution of silicoflagellates in the Gulf of California. Cienc. Mar. 14:9–38.

Salas de León, D. A., N. Carbajal, M. A. Monreal-Gómez, and A. Gil-Zurita. 2011. Vorticity and mixing induced by the barotropic M2 tidal current and zooplankton biomass distribution in the Gulf of California. J. Sea Res. 66:143–153.

Sánchez-Velasco, L., E. Beier, V. M. Godínez, E. D. Barton, E. Santamaría-del-Angel, S. P. A. Jiménez-Rosemberg, and S. G. Marinone. 2017. Hydrographic and fish larvae distribution during the "Godzilla El Niño 2015–2016" in the northern end of the shallow oxygen minimum zone of the Eastern Tropical Pacific Ocean. J. Geophys. Res. Oceans 122:2156–2170 (doi:10.1002/2016JC012622).

Sánchez-Velasco, L., J. E. Valdez-Holguín, B. Shirasago, M. A. Cisneros-Mata, and A. Zarate. 2002. Changes in the spawning environment of *Sardinops caeruleus* in the Gulf of California during El Niño 1997–1998. Estuarine Coast. Shelf Sci. 54:207–217.

Santamaría del Angel, E., S. Álvarez-Borrego, and F. E. Müller-Karger. 1994. The 1982–1984 El Niño in the Gulf of California as seen in coastal zone color scanner imagery. J. Geophys. Res. 99:7423–7431.

Schiermeier, Q. 2015. Hunting the Godzilla El Niño. Nature (Lond.) 526:490–491.

Stramma, L., T. Fischer, D. S. Grundle, G. Krahmann, H. W. Bange, and C. A. Marandino. 2016. Observed El Niño conditions in the eastern tropical Pacific in October 2015. Ocean Sci. 12:861–873 (doi:10.5194/os-12-861-2016).

Whitney, F. A. 2015. Anomalous winter winds decrease 2014 transition zone productivity in the NE Pacific. Geophys. Res. Lett. 42:428–431 (doi:10.1002/2014GL062634).

Wolter, K., and M. Timlin. 2011. El Niño/Southern Oscillation behavior since 1871 as diagnosed in an extended multivariate ENSO index (MEI.ext). Int. J. Climatol. 31:1074–1087.