# Climate change and the mechanisms behind larval success, recruitment and commercial catch for the Dungeness crab, *Cancer magister*.

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**Abstract**

We have 23 years of daily light trap sampling of Dungeness crab megalopae, (*Cancer magister*,) in Coos Bay Oregon. The annual megalopae catch varied from ~2,000 to 2.5 million, a factor of ~3,000. Lowest catches occurred during strong El Niño years. Megalopae catch is significantly correlated to the PDO (more caught during negative PDO), the day-of-the year of the spring transition (more caught with an early transition), and the amount of upwelling during the settlement season (more caught with more upwelling). Annual catch of megalopae is significantly correlated to commercial catch of crabs four years later and takes the form of two curves, years with <100,000 megalopae caught (>80% variability explained) and years with >100,000 caught (>70% explained). Using these correlations, we can make accurate predictions (±12%, SD 9%) of the commercial catch four years in advance. However, our predictions underestimate by about a factor of 1.5 in years with spring/summer marine heatwaves. We hypothesize that young crabs grow faster and have higher survival during marine heatwaves. An index of recruitment success (Index = #crabs/megalopae catch) varies strongly with the abundance of settling crabs. It is orders of magnitude higher (Index = ~3,000 crabs/megalopae) at low annual megalopae catch (<3,000) than at high annual catch (>millions megalopae caught) (Index = ~5 crabs/megalopae at). This variation in recruitment success may explain the two correlations between megalopae catch and fishery catch. Annual megalopae catch in Oregon predicts the commercial catch in California, but not Washington.

## Introduction

Climate change is altering the oceans. In the Northeast Pacific Ocean, marine heatwaves have become regular events and the effects are being felt throughout the ecoregions (1). These changes have the potential to greatly influence the population dynamics of species in the region including commercially important species. In the California Current ecoregion, many of the economically important species have demersal adults with pelagic larvae; a changing ocean may strongly affect these larvae. The Dungeness crab *(Cancer magister*) is the most economically important single species commercial fishery in Oregon (2) and an ecologically important component of the benthic community. For 23 years, we have been measuring the daily and annual abundance of Dungeness crab megalopae (the final larval phase) using a light trap on the Oregon coast. This unique data set is providing a better understanding of how climate change and hydrodynamic variables affect this important species.

This monitoring study has led to several previous papers (3-8). The last paper focusing on the light trap work presented data from the first 12 years of the study (5), hence, this present publication almost doubles the length of the published light trap results (i.e., 11 additional years of data). The data consists of daily counts of the number megalopae caught in a light trap (Figure 1) fished in Coos Bay, Oregon during the Dungeness crab settlement season (~April through September). These data have been used to address a number of questions; 1) the day-to-day variation in the catch has been used to investigate the mechanism facilitating the onshore transport of the megalopae, 2) to investigate the causes of annual variation in the number of megalopae caught in the trap (i.e., larval success), the year-to-year variation in the total number of megalopae caught has been compared to climactic and hydrographic variables (e.g., Pacific Decadal Oscillation (PDO), El Niño, upwelling, spring transition), 3) the annual catch of megalopae has been used to predict the Oregon commercial ocean crab fishery catch or, from a more ecological perspective, the size of the four-year-old age class. In addition, we use these data to investigate variation in recruitment to adulthood, i.e., how likely is it that a settling megalopae may survive to adulthood. In the remainder of the introduction, we will briefly describe the relevant life history traits of the species, how the species is fished, what we have learned thus far and indicate how the additional data reported here may affect these insights.

Dungeness crabs reach sexual maturity at approximately 1.5 to 2 years (9). Mating occurs in the spring and early summer. Female crabs release pheromones when they are close to molting. Male crabs 'capture' females near molting and hold them (i.e., pre-mating embrace) until molting at which time mating occurs. A male crab can mate with multiple females and the female stores the sperm until fall when she extrudes and fertilizes eggs (10). Previous work has shown sperm, if stored by the female, may be viable for up to 2.5 years; some individuals skip annual mating and fertilize eggs with stored sperm. Females extrude between 1.5 to 2.5 million eggs and the number extruded is independent of carapace width (11). In the waters off Oregon, egg development takes three to four months and the eggs hatch in winter (January through March). Zoea larvae are released into the coastal waters where they are transported northward by the Davidson Current, the current present over the continental shelf in winter (Figure 1). Over their development, larvae are found progressively further from shore (12) until they are seaward of the shelf and in the southward flowing California Current (Figure 1). Hence, during the pelagic phase, the larvae are first transported to the north and then to the south. There are five zoeal stages after which they metamorphose into a megalopa (13). The megalopae are large (almost 1 cm carapace width), and fast swimming (> 10's cm/sec swimming speed) (14, 15). The pelagic larval duration is ~90-120 days depending on ocean temperatures (9). In central Oregon, megalopae generally start to arrive in nearshore and estuarine waters in late

March or early April. They settle and molt into juvenile crabs along the open coast and within estuaries. In most years, they continue to arrive at the coast through August/September. During the first months the young crabs go through ~6 molts and grow rapidly from about 5-7 mm to 40 mm carapace width in the late summer and fall (9, 16).

A history of the fishery can be found in Wild and Tasto (17) and Rasmuson (9). The current fishing regulations have been in effect for decades and are simple (9). Crabs are caught with baited traps or pots. Only male crabs with a carapace width larger than about 16 cm carapace width (CW) are kept (9). All female and smaller male crabs are returned to the ocean and survival of returned crabs is high (18). Nearly all legal-sized male crabs are caught each year (19). In Oregon waters, these male crabs are about four years old, hence, they have been able to mate in at least one and perhaps two seasons. Several studies have demonstrated that nearly all female crabs are fertilized each year either because they mated in that year or had stored sperm from an earlier mating in a previous year (8). The fishery is seasonal with start dates varying along the coast. The Oregon commercial ocean fishery start date is 1 December (2) but can be delayed if legal size male crabs have not returned to a sufficient weight (filled out) following the fall seasonal molt or if they have been contaminated by domoic acid (8). The fishing season runs through August 14 (2) and is closed before the fall molt cycle commences. The fishery is a derby with most of the crabs caught within a couple of months of the opening date. The fishing regulations are surprisingly effective; despite the intensity of the fishery, there is no impact on the reproductive output of the population since no females are retained, and fertilization rates are high each year. Because reproductive output is not impacted, over the 100 plus years these fishing regulations have been in effect there is no indication that the population in the California Current has been over fished (20).

In most years, megalopae begin showing up in the light trap in early April. In some years megalopae return is delayed by a month or more. Daily catch generally starts out low, tens to hundreds of megalopae per day, but within several weeks increases to the maximum daily catch for that year (see supplemental material for plots of the daily catch for each of the 23 years sampled). The daily catch is highly pulsed and follows a fortnightly periodicity (2-6). We see low catch for five to 10 days and then for several days or longer during a pulse the daily catch jumps by one to several orders of magnitude. During the entire time series, the day-to-day variation in catch has been significantly cross-correlated with the daily tidal range (21). Peak catches tend to occur between the neap and spring tide or shortly after the spring tide (varies from year to year) (17). Given the day-to-day variation in the catch, the most likely mechanism of cross-shelf transport of the megalopae is via internal waves generated by the tides, the internal tides (17).

We concluded from previously published papers (5, 6) that the year-to-year variation in the number of megalopae caught during the settlement season was primarily driven by the Pacific Decadal Oscillation (PDO), the day-of-the-year (DOY) of the spring transition, and the amount of upwelling during the settlement season. The number of megalopae caught during the settlement season varied by a factor of >1,000 with larger catches tending to occur during years with a negative PDO, early spring transition, and more upwelling (5). The lowest catch (< 2,000 megalopae) occurred during the strong El Niño in 1997 and the largest catch (2,400,000 megalopae) during a negative PDO.

We hypothesized that the PDO and El Niño alter the annual larval success by their effect on the relative north south transport of the larvae (5, 9). During their pelagic development, larvae are first transported north in the Davidson Current, then south in the California Current. The number of megalopae that arrive at the coast at Coos Bay may thus be dependent on the relative amount of north and south transport the larvae experience.

During a strong El Niño, when there is an enhanced Davidson Current, larvae may be carried far to the north potentially to the Gulf of Alaska (22) leading to low larval returns in Oregon. In contrast, during a strong negative PDO, when the California Current is faster, the southward component of the migration is augmented, and more larvae are caught in the light trap in Coos Bay. This hypothesis was supported by the results of a modeling experiment (23).

In earlier papers (5, 6), we hypothesized that megalopae in the ocean seaward of the continental shelf were carried onto the shelf by deep currents generated by wind driven coastal upwelling. This hypothesized onshore transport would occur sooner with an early spring transition and more often with increased upwelling, both of which may lead to higher abundances of megalopae. However, a study by Rasmuson and Shanks (21) suggested an alternate hypothesis, the hydrodynamics during upwelling is conducive to the shoreward transport of the megalopae. In the winter months, due to storms, the thermocline is deeper and the tidally generated internal waves, the likely onshore transport mechanism, formed do not cause transport (24). At the spring transition and during upwelling, the thermocline is shallower which may allow for the generation of transporting internal waves or internal bores (21) that carry megalopae across the shelf to the coast.

In our first published study (8) we tested the hypothesis that the size of the four-year old age class (legal-sized male crabs) was set by the number of returning megalopae, i.e., the annual catch in the light trap. Surprisingly, with just five years of data we found a very strong positive regression between the catch of megalopae and the catch in the fishery in Oregon. Interestingly, we also found a positive relationship between megalopae catch in Coos Bay, Oregon and the commercial ocean catch in California, but not the commercial ocean catch in Washington (8). The relationship between catch of megalopae and Oregon crab catch held up in the next two published papers (5, 6). The data presented here continues to support this conclusion, however, the relationship between the returning megalopae and age class strength has become more complex and interesting.

In this study, we present an expansion of our time series of larval returns to Coos Bay, Oregon as measured by daily catches to a light trap from a 12 to a 23-year time series. We analyze these data to better understand the hydrographic causes of year-to-year variation in annual larval success and how this variation in success translates into age class strength (recruitment) and fisheries catch.

## Materials and Methods

A detailed description of the sampling methods used from 1997 to 2001 can be found in (6, 8). Identical sampling methods have been used since the time series was restarted in 2006 through to the present. Megalopae were caught using a light trap placed at the end of F dock in the Charleston small boat harbor in Coos Bay, Oregon (43° 20' 41" N, 124° 19' 15" W) (Figure 1). In the initial study, we fished replicate traps at several locations within the estuary (8). The pattern of catch was similar at the different locations within the estuary and the abundance in replicate traps at a location were also similar. The largest catches were at the site closest to the mouth of the estuary, F dock. To allow for efficient sampling, critical for a long time series, since 2006 we have fished one trap.  In 2000, traps fished simultaneously in the estuary and the ocean demonstrated that the pattern of daily abundance did not differ between the open coast and within the estuary (25). Each year, the trap was fished from roughly the beginning of April through September, the local settlement season for *C. magister*, and megalopae were removed from the trap daily. The total number of megalopae captured in each settlement season was used as an index of the abundance of megalopae returning to the coast, i.e., annual larval success. When a daily sample of megalopae was < 2000 either the entire sample was counted or it was split using standard methods and then counted) (26). Starting in 2007, the daily and annual abundance of megalopae increased dramatically with daily catches during pulses on the order of 10s of thousands of megalopae (i.e., liters of megalopae in the light trap). We could not efficiently count these huge samples. To estimate the number of megalopae, we carefully drained off the water, weighted the entire sample, and then divided by the weight of 100 megalopae. This method was validated by counting entire samples on multiple occasions.

To test the hypothesis that adult population size was limited by the number of returning megalopae, we correlated the index of settling megalopae (i.e., the summed daily catch of megalopae) to the size of the Oregon, Washington and California commercial catch landed four years later, the time needed for megalopae to recruit into the fishery (20). The California Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, , and the Washington Department of Fish and Wildlife provided annual commercial catch data for each state. During the annual fishing season, essentially all legal sized male crabs are caught (19), hence, the size of the commercial catch is an excellent measure of the four-year old class.

To investigate the causes of the annual variation in the abundance of megalopae caught in the light trap we regressed the catch data with physical variables including the DOY of the spring transition, the PDO index, an El Niño index, and the Coastal Upwelling Transport Index (CUTI). The DOY of the spring transition was calculated using the methods described in Shanks and Roegner (8). Average daily sea level data for Crescent City, California was obtained from https://uhslc.soest.hawaii.edu/. The average annual sea level was calculated for each year and subtracted from the daily average sea level. The spring transition was the date after which there were at least seven days with sea level 100 mm lower than the annual average (27). During strong El Niños, sea level at the coast is elevated. This appears to confound our method of determining the spring transition date. For example, in 1997, a year with a strong El Niño, this method produced a DOY of the spring transition of only 35 days, very early. For the DOY of the spring transition in the two years with strong El Niño conditions (1997 and 2016) we used data from Pierce and Barth (Shadow.ceoas.oregonstate.edu/damp/windstress/). In their calculations they use cumulative wind stress to define the spring transition (see their web page for methods). Data on the PDO index and the CUTI upwelling index for 45° north were obtained from internet sources (PDO - http://research.jisao.washington.edu/pdo/PDO.latest, CUTI - https://rdrr.io/github/marinebon/ecoidx/man/cciea_OC_CUTI.html). For an El Niño index we used the Oceanic Niño Index (ONI) (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). The PDO index was summed for the period Dungeness crab larvae are pelagic, roughly January through July. For the CUTI we summed from March through July, the period when megalopae return to the shore and are caught in the light trap. For the ONI index we summed the monthly values for the entire year.

To understand the relationship between the above variables and the number of returning megalopae each year we used generalized additive models (28). The PDO and the El Niño index are significantly correlated ($R^2$=0.64, n=23, P<0.00001). Because the two indices are correlated, we did not include the El Niño index as a potential variable in our GAM analysis and acknowledge the difficulty in disentangling the relationship between the two variables. Models were fit using the mgcv package in R version 4.3.2 "Eye Holes" (29) and a Tweedie distribution. Explanatory variables included in the model were CUTI, DOY of the spring transition, and PDO. Prior to model fitting we ensured there was no concurvity between the variables. The variables were modeled as smoothed variables and were restricted to 5 knots to prevent overfitting of the data. All possible models were fit and compared using the corrected Aikake information criterion (AICc) (30). The fit of the best fit model was analyzed using the DHARMA package (31).

**Results**

On average, the first returns (i.e., catch) of Dungeness crab megalopae occurred on 9 April, (range 28 March, 2015, to 24 April, 2008) and 90% of the annual catch of megalopae occurred by 15 June, the latest date was 26 August (2012) (plots of daily catch and cumulative catch are presented in the supplemental material). Ninety percent of the megalopae were caught, on average, in just 67 days (range 32 (2017) to 146 (2012) days).

The year-to-year variation in the total number of megalopae caught is extremely large (Figure 2A). Annual catches of megalopae, a measure of larval success, have ranged from a low of just over 1,000 animals to highs of almost 2,800,000; larval success, varies by a factor of close to 3,000. During years with low returns, a one-night catch during a pulse is a few tens of animals, but during a year with high returns daily pulses are often liters of megalopae, >10,000s of individuals per day. When viewed as a frequency plot (Figure 2B), the distribution of annual catch of megalopae appears to be bimodal. What causes these extremes in megalopae abundance and why is the distribution bimodal?

The lowest catches of megalopae occurred in years with strong El Niños (1997 and 2016); perhaps larval success varies with El Niños. The relationship between an El Niño index and larval success, catch of megalopae, is a parabolic curve (Figure 3) with 50% of the annual catch explained by the El Niño index. The lowest annual catches of megalopae occurred during the two strong El Niños when less than 3,000 animals were caught (Figure

2). Lower catches also occurred when the index was highly negative while peak catches occurred when the index was between about zero and -5 (Figure 3).

From regression analysis we found that the variability in the number of megalopae caught annually was explained by the PDO, the CUTI upwelling index, and the DOY of the spring transition (regressions explained 44, 12 and 33% of the variability, respectively) (Figure 4). Peak annual catches of megalopae occurred when the summed PDO index was negative, but, when the PDO index was very negative (>-12), catch dropped off (Figure 4). The catch of megalopae was lowest when the PDO index was positive (Figure 4). Higher catches of megalopae tended to occur when the spring transition was earlier (Figure 4). For example, in years when we caught more than a million megalopae, the spring transition occurred before mid-March. The relationship to the CUTI, while statistically significant, was weak (Figure 4). There was a weak tendency for higher catches to occur when there was more upwelling.

The best fit GAM included PDO, CUTI and DOY of the spring transition, though the second-best fit model that included just the PDO and DOY of the spring transition differed by < 2 AICc units. We present the results from the best fit model (Figure 4). The model explained 63.1% of the variability in the data. PDO had a consistent effect on returning megalopae from the lowest values to a value of ~5 at which point the influence of PDO declined (Fig. 4A and B). For the upwelling index, as upwelling increased from 2 to 4 there was a positive effect on the number of returning megalopae (Fig. 4C, D). Above a value of 4, upwelling had a declining influence on the number of returning megalopae (Fig. 4C). For the DOY of the spring transition there was a negative relationship with number of returning megalopae (Fig. 4F).

In the California Current, Dungeness crab larvae hatch during the winter and are pelagic for 3 to 4 months (9). Given hatch dates and the pelagic larval duration, we should not catch any larvae from the California Current population by the end of July. The date when we have caught 90% of the megalopae within a year (20 July) likely reflects this cut off in the presence of larvae from the California Current. To the north of Oregon, in British Columbia and the Puget Sound/Salish Sea, the larval hatch occurs later by one or more months (9), hence, megalopae caught late in the summer may be animals from these more northern populations. During negative PDO's, the California Current is stronger due to the influx of additional water from the North Pacific Drift and this enhanced southward flow may transport larvae spawned to the north to Oregon. We summed the number of megalopae caught annually in the settlement season (20 July, average date when 90% of megalopae were caught plus one SD), summed the monthly PDO index for the same period and ran regressions between the two data sets (Figure 5). Using all the data the regression was not significant, however, one data point (year 2022 data, x in the lower lefthand corner of the graph) is more than two standard deviations below the regression line suggesting that it is an outlier. With this data point removed, the regression is significant with the PDO index explaining 35% of the variability in the catch of megalopae late in the summer. During years with negative PDO and, hence, stronger southward flow in the California Current, we catch more megalopae whose source must be to the north of Oregon.

The settling megalopae will eventually grow into legal-sized crabs that will enter the fishery. In the California Current population, this takes four years. Hence, the number of settling megalopae caught each year may predict the size of the commercial catch four years in the future. Figure 6 shows the $\log_{10}$ megalopae catch in Coos Bay per settlement season plotted with the $\log_{10}$ of the commercial catch of Dungeness crabs in Oregon four years later. The distribution of data points suggests that there are two curves, one associated with data from annual catches of megalopae <100,000 and a second associated with years with catches >100,000 (Figure 6). In the online supplemental material, we show

how this relationship evolved over time leading to our realization that the relationship is made up of two curves dependent on the number of megalopae caught. Both curves are significant and explain from 70 to 90% of the variability in catch or the size of the 4-year-old age class of crabs.

There have been a number of marine heatwaves on the Oregon continental shelf during the time series (https://www.integratedecosystemassessment.noaa.gov/regions/california-current/california-current-marine-heatwave-tracker-blobtracker). A marine heatwave is defined as a 'prolonged discrete anomalously warm water event that can be described by its duration, intensity, rate of evolution, and spatial extent' (32). Thus far we have five paired data points, number of megalopae caught coupled with the subsequent commercial catch, for marine heatwaves in 1997, 2014, 2016, 2019, and 2020. There were likely marine heatwaves on the shelf in 2021-2023 as well, but the megalopae that settled in those years have yet to enter the fishery. In Figure 6, the data from the marine heatwave years are plotted as X's and each of these data points falls well above the established regression relationships generated from the 18 years of data when there were not marine heatwaves. The data from the marine heatwave years were not used in the calculations of these regressions. These data suggest that the probability that settled larvae will survive to adulthood, recruitment, is higher when there was a marine heatwave.

The relationships between the number of megalopae returning to the coast and the subsequent size of the four-year old age class as indicated by the commercial catch is robust, the number of megalopae caught, an indicator of larval success, is a good predictor of commercial catch four years later. To test just how good a predictor, we plotted the predicted commercial catch calculated from the equations in Figure 6 (note that this calculation was made in the settlement year, so four years prior to the fishery) against the actual observed catch (Figure 7). The size of the annual catch of megalopae explains >82% of the variation in the observed catch; the regression line falls almost on top of the one-to-one relationship. On average, excluding the marine heatwave years, our estimated commercial catch is within ±12% (SD 9%) of the observed catch.

In this analysis we left out the data from the marine heatwave years (filled squares in Figure 7). These data points fall above the one-to-one line and the regression line. The observed catch are about 3,000 metric tons (approximately 3.5 million additional male crabs) higher than that calculated by the regressions. These five data points form a significant regression explaining 99% of the variation, but with just five data points this regression should be treated as tentative. Over time, with continued marine heatwaves, we may see curves composed of marine heatwave data.

The fact that there are two curves relating the number of returning megalopae and recruitment into the four-year old age class (Figure 6) suggests that in years with lower returns of megalopae a higher percentage of settlers survive to recruit than in years with high megalopae returns. To investigate this, we plotted the annual megalopae catch against an index of recruitment success (i.e., the total number of crabs caught in the fishery divided by the number of megalopae caught in the light trap four years prior) (Figure 8). The number of crabs caught was simply the total commercial crab catch in Oregon in kilograms divided by the average weight of a male crab in kilograms (0.84 kg., Oregon Department of Fish and Wildlife). Plotted as $\log_{10}$ data, the relationship is highly significant. The regression line is composed of four clusters of points. 1) When the number of megalopae caught was around several thousand (the years with strong El Niños), the index is several thousand (Figure 8, cluster 1 in the graph), 2) between several thousand and 100,000 megalopae caught the index is in the hundreds (Figure 8, cluster 2 in the graph), 3) At >100,000 to 1 million megalopae caught the index drops to tens (Figure 8, cluster 3 in the graph), and 4)

At >1 million megalopae caught, the index is in the ones (Figure 8, cluster 4 in the graph). In Figure 6, the left-hand curve is defined by variations in our index of recruitment success from hundreds to thousands (data clusters 1 and 2) while the right-hand curve is defined by index values of from ones to tens (data clusters 3 and 4).

The hydrographic variables that appear to be driving the year-to-year variation in the abundance of returning megalopae, the PDO, ENSO, CUTI and DOY of the spring transition, all vary in a similar pattern and simultaneously across the California Current system. This suggests the possibility that the annual variation in the number of megalopae returning to locations along the west coast could be similar to that seen in Coos Bay. If this were the case, then we might be able to predict the size of the four-year old age class /commercial catch in California and Washington from the megalopae catch in Coos Bay.

Plotting the light trap catch of megalopae in Coos Bay against the commercial catch (four-year old males) in California (Figure 9A) we find a relationship very similar to what we find in Oregon (Figure 6). There are two curves; one describing the relationship when <100,000 megalopae were caught and a second curve describing the relationship when >100,000 megalopae were caught (Figure 9A). Both curves are significant and the megalopae catch in Coos Bay explains about 68% of the variability in California commercial catch. In contrast, we found no significant relationship between Coos Bay megalopae catch and commercial catch from ports on the Washington coast (Figure 9B, open circles). In Oregon through the range of California inhabited by Dungeness crabs (south to Morro Bay), the crab population appears to respond similarly to the hydrography of the California Current (Figure 9C) while the Washington outer coast does not (Figure 9D). A regression between the commercial catch in Oregon and California is significant and explains about 33% of the variability ($R^2$=0.329, n=15, P<0. 026). Similar regressions run between the

Oregon catch and those in Washington, open coast, and Columbia River ports, were not significant.

## Discussion

*Larval transport*

Over the 23-year time series, the number of megalopae caught during the settlement season has varied from a few thousand to almost three million, a variation of almost 3,000 times. Two questions arise. First, what might cause these huge variations in the settlement of megalopae? Surprisingly, while the number of settling megalopae determines the size of the four-year-old age class (i.e., the commercial catch) between the lowest and highest commercial catch, the variation is only a factor of ~5. This observation leads to a second question. Why might the variation in commercial catch be so much smaller than that of the megalopae settlement, a variation of ~3,000 times compared to a variation of only ~5 times? In the following we will present hypotheses that might answer these two questions.

The variation in the number of megalopae settling each year appears to be largely driven by variations in hydrodynamics that affect the north and south transport of zoea and the cross-shelf transport of megalopae. Our model shows that PDO, CUTI upwelling index and DOY of the spring transition explains 63% of the variability in the data; the complex interaction between these three hydrodynamics processes appears to largely determine the number of settling megalopae.

As a reminder, larvae are released in winter over the continental shelf. The actual distribution of larval release sites is unknown, but larval release is likely concentrated toward the shore rather than the shelf break. Larvae released over the shelf during the winter will be carried northward by the Davidson Current. Drifter data suggest that northward transport during this period could be substantial (33). As larvae develop, they move further offshore until they are off the shelf and in the southward flowing California Current (12). Thus, the larvae are first transported north (Davidson Current) and then south (California Current). We hypothesize, and biophysical modeling work supports this hypothesis (21), that the number of megalopae caught in Coos Bay is in part dependent on the relative amount of north and south transport the larvae experience. The two years with the lowest number of returning megalopae were years characterized by strong El Niño events; northward transport would have been enhanced relative to non-El Niño years. Larvae may have been carried far to the north. In fact, larvae from the California Current have been caught off the coast of Alaska (22). We found a significant regression between the PDO and the annual catch (Figure 4B); lower catches when the PDO was positive, less southward flow in the California Current, and higher when it was negative, more southward flow in the California Current. In other words, when the PDO is negative the larvae are more readily transported back south and more megalopae settle in Oregon coastal waters. The fact that the late season catch of megalopae is also correlated with the PDO (Figure 5), more late-megalopae during negative PDOs, lends support to this hypothesis. In the regression (Figure 4B), notice that during very negative PDOs catch in Oregon tended to be lower. Perhaps the southward transport is so strong that larvae tend to be transported past Oregon and more settle on the California coast.

We developed a biophysical model of dispersal to investigate the hypotheses we generated from the light trap data (24). During positive PDOs, the model indicated that more larvae were lost from the model domain north into the Alaska Current (23). Further, more larvae settled north of their larval release site in positive PDOs, however, the average transport was still southwards. In other words, larval settlement was, in general, more diffuse than during negative PDOs. Interestingly, we also found that during positive PDOs, perhaps due to the warmer water temperature, larvae molted into megalopae faster but remained in the water column longer (23). While we did not model this explicitly, a longer time as a megalopae could result in increased predation by planktivorous fishes.

The DOY of the spring transition and the CUTI index are correlated with the number of megalopae caught. Both variables relate to different aspects of the upwelling season; the spring transition is the date on which the winter wind pattern (downwelling favorable) shifts to the spring/summer upwelling-favorable wind pattern. CUTI is an index of the amount of upwelling occurring. We hypothesize that the shallower depth of the thermocline during upwelling, sets up conditions favorable to the shoreward transport of megalopae. It is worth noting the relationship between the number of megalopae and the CUTI upwelling index differed between the GAMs (negative linear relationship) and simple linear regressions (positive linear relationship). This combined with the fact that the model without CUTI was < 2 AICc units different from the best fit model suggests weak support for the CUTI index being included in the model. Since we hypothesize this relationship is more reflective of changes in the water column structure rather than the upwelling process, this is, perhaps, not surprising.

The daily catch of megalopae is highly pulsed with catch varying by an order of magnitude or more over a few days. The pulses tended to occur roughly every two weeks and are significantly correlated to the spring neap tidal cycle (21). This can be seen particularly clearly in daily data from 2006 and 2023 (Supplemental Material). Fortnightly pulses correlated with the tides, that is out of phase with the spring neap cycle, and not proportional to the tidal amplitude is an indication that onshore transport is likely due to the internal tides (34-36). Tidal flow off the continental shelf produces packets of large internal waves, collectively known as the internal tides (37). These large internal waves can produce moving surface convergences capable of transporting surface material, neustonic larvae, and floating flotsam (34, 38, 39), shoreward. In addition, they can produce broken internal waves or internal bores that can transport water and entrained animals shoreward (40).

*Recruitment into the fishery*

We have analyzed the relationship between the number of megalopae caught and the commercial catch as two regressions (minus the marine heat wave years, Figure 6) (see Figure 2 in the supplemental material for additional discussion). Both curves are significant with the number of megalopae settling explaining from 80% (<100,000 megalopae caught) to 70% (>100,000 megalopae caught) of the variability in the commercial catch. These data lead to three questions. 1) Why are there two curves? 2) The $\log_{10}$ scale of number of megalopae caught (horizontal axis, Figure 6) ranges from 2.5 to 6.5 yet the $\log_{10}$ scale on the commercial catch (vertical axis, Figure 6) ranges from just 3.2 to 4.2. Why is the commercial landing so much less variable than the number of megalopae caught? 3) In Figure 6, there are five data point indicated by Xs. These data are from years when there were marine heatwave conditions over the continental shelf. The points fall well above the two regression lines. What is happening?

Why are there two curves (Figure 6)? The most likely explanation is that recruitment success varies with the number of settling megalopae, with lower recruitment when settlement is higher. To investigate this, we plotted a crude index of recruitment success (number of crabs caught in the fishery/number of megalopae caught in the light trap) vs. the number of megalopae caught (Figure 8). The index of recruitment success dropped sharply as the number of megalopae caught rose, ranging from around 3,000 crabs/megalopae during the low megalopae catches of the El Niño years to just around 5 crabs/megalopae during the years with millions of megalopae caught. In Table 1, we have made up a set of model data in which we picked megalopae catch over the full range of annual catch (i.e., <3,000, 10,000s, 100,000s, millions), and multiplied this catch by the recruitment index (Figure 8) to get the number of legal sized male crabs (Table 1). At low larval returns, the high recruitment success, despite the low number of megalopae, generates a substantial number of crabs and, as the number of returning megalopae goes up and the recruitment success goes down, there is still a substantial number of crabs produced. But at the transition from 90,000 to 100,000 megalopae caught, there is almost a four-fold drop in recruitment success leading to a sharp drop in the number of crabs produced, e.g., a drop from 22.5 to 6 million crabs (Table 1). The combined effect of sharply decreasing recruitment success with increasing numbers of returning megalopae appears to be the cause of the two regression lines in Figure 6.

Mathematically this explains the two curves in Figure 6 and why the commercial catch, i.e., the four-year-old age class, is so much less variable than the number of megalopae caught, but these observations beg the question, what is the biological mechanism that causes this relationship between megalopae and adults, recruitment. A dramatic decline in a population when a threshold is exceeded is quintessential density dependence (41). Undoubtedly, the relationship will be explained by the differential survival of juvenile crabs, but the curious drop in apparent survival between 90,000 megalopae caught in the light trap and 100,000 suggests the relationship is not simple. Even though the Dungeness crab fishery is one of the most profitable single species fisheries on the west coast and the species is ecologically important, we know surprisingly little about their biology after they settle and molt into young crabs. Much of the research that has been done on this critical phase has occurred in estuaries and the intertidal even though most of the population settles in the subtidal and on the open coast (42-44). As this paper indicates, we have decades of useful data on the relative larvae success, i.e., megalopae abundance, but similar data for recruitment is absent. Between the megalopae returning to shore and the commercial catch, there is a black box.

Confronted with this black box, we are reduced to hypothesizing what might be occurring within the box. There are several likely critical observations, the arrival of megalopae to the shore is highly pulsed (Daily settlement data, Supplemental Material), there have been frequent observations of extremely dense aggregations of juvenile crabs (100s to 1,000s/$m^2$) on the seafloor (45), and juvenile crabs are actively cannibalistic (46). We hypothesize that following a pulse of megalopae arriving at the shore, there is a sudden influx of newly molted crabs (i.e., megalopae metamorphosing to crabs) on the bottom. The size of this influx may be proportional to the size of the pulse of megalopae caught in the light trap. During this transition from a pelagic to benthic habitat, the megalopae molt at which point they are likely easy prey to cannibalistic young crabs already on the bottom. In addition, each time a young crab molts and is briefly a soft shell crav, it is again vulnerable to predation by cannibalistic congeners. We hypothesize that during years with low megalopae returns, the density of young of the year crabs is much lower and predatory cannibalistic interactions between the juvenile crabs is lower (47). In contrast, during years with high returns and regular large pulses of settling megalopae, predatory interactions may be continuous throughout the settlement season. During years with low returns, the food supply may be better than in years with high returns and this would also impact the rate of cannibalism. Recent work has even suggested that cannibalism enhances stability of populations with large boom and bust cycles (47). In this scenario, smaller, more recently settled crabs, may be at a disadvantage relative to larger individuals that settled earlier (44, 46, 48). Another possibility is that during years with many settlers, food is scare and young crabs starve. This is not an alternate hypothesis (49) as starving crabs are likely more susceptible to predation by cannibalistic congeners and cannibalism is likely higher due to a lack of alternate food. While cannibalism is well known in juvenile crabs in their first year, it is unclear how cannibalistic older adults are.

The relationship between megalopae settlement and commercial catch, i.e., the four-year old age class, is altered during marine heatwaves; during marine heatwaves, more settlers survive to become adults and enter the fishery. In other words, mortality rates of YOY crabs appears to be lower during marine heatwaves. It is possible that with the now regular occurrence of marine heatwave years that such data will eventually generate additional curves, curves displaced upward from the curves generated by data from non-marine heatwave years.

This leads to our third question, why has recruitment during marine heatwaves been more successful than during years with more normal seawater temperatures? In 0+ and 1+ (i.e., young of the year and year-old crabs, respectively), warmer water leads to higher metabolism and faster growth (16). Most marine heatwaves have been identified from satellite measurements of surface temperatures, but to affect the benthos and the juveniles crabs, the heatwave must extend to the bottom and on the Oregon coast this appears to be the case (50). Hence, during a marine heatwave, young of the year crabs likely grow more rapidly through the smaller early molts and reach sizes that are less susceptible to predation, particularly predation by cannibalistic congeners. This would cause an increase in recruitment success, which would, in our calculations, appear as a higher-than - predicted commercial landing.

The snow crab (*Chinoecetes opillio*) population in the Bering Sea has declined to the point that the fishery for the crab has been closed (51). There have been several explanations proposed for this decline: including over-fishing and that the adult crabs migrated to cooler, deeper water due to marine heatwaves. A recent and, perhaps, the most likely explanation is the following scenario (51): following a strong recruitment event there were marine heatwaves. The metabolic rate of the adult crabs was elevated in the warmer water causing higher feeding rates. The large population of abnormally hungry crabs simply consumed all the available resources and starved to death.

The California Current Dungeness crab population has been affected by repeated marine heatwaves and during these events our data suggests the crab population has experienced enhanced recruitment. Since the metabolic rate of Dungeness crabs increases in warmer water (16), conditions similar to that observed in Snow crabs could be occurring. Could a similar marine heatwave induced die off, as seen in Snow crabs, occur with Dungeness crabs? We do not have enough data to answer this question, but we do have evidence suggesting that recruitment is about 1.5 times higher during marine heatwaves. During the two marine heatwave years with the highest catch of megalopae, the enhanced recruitment was equal to about 8 million additional male crabs (fishery is limited to males) or total (male plus female crabs) about 16 million additional crabs in the Oregon coastal waters. 2023 was a year with very high megalopae catch (~2.5 million megalopae) and a marine heatwave. If recruitment in 2023 is similarly enhanced as in previous marine heatwaves, then the population may receive an estimated 30 million additional crabs. Marine heatwaves are occurring regularly (i.e., 2015, 2016, 2019, 2021, 2022, 2023). Several marine heatwaves in a row may mean that the recruitment to the adult population is repeatedly being enhanced. As with the Snow crabs, these adult crabs will be living in warmer than normal waters with a higher metabolic rate with a consequent increase in their food requirement. Could the California Current Dungeness crabs follow the same fate as the Bering Sea Snow crab? Without data on warm water changes to Dungeness crab food intake, their population density, and the food resource density there is no way to know.

The Coos Bay light trap catches are significantly correlated with commercial catch in California, but not Washington (Figure 9). The relationship between Coos Bay megalopae catch and California commercial catch looks remarkably like the relationship between Coos Bay megalopae catch and Oregon commercial catch. The number of megalopae caught in Coos Bay is primarily driven by El Niño (lowest catch during strong El Niños), the PDO, the DOY of the spring transition, and the amount of upwelling during the settlement season. From Oregon south along the California coast to the Southern California Bight, these variables fluctuate synchronously. Hence, when the catch of megalopae is high in Coos Bay due to a negative PDO, early spring transition and consistent upwelling or the megalopae catch is low due to a strong El Niño, similar conditions are present in California, and they appear to affect the California Dungeness crab population similarly.

The Washington coast is no further away from Coos Bay, Oregon than the California Coast, the Washington coast is still within the California Current system and the driving hydrographic variables tend to vary in synchrony here as well. So why is there not a significant correlation between the Coos Bay megalopae catch and the Washington commercial catch? We are not sure. Washington has a wider continental shelf than Oregon. The Washington continental shelf is bifurcated by many large deep marine canyons (52, 53). These two variables may affect the cross-shelf movement of larvae. Or the difference may be due to a significant change in the coastal oceanography that occurs at the Washington-Oregon border. The border between Washington and Oregon is defined by the Columbia River, a very large river. In the winter, when Dungeness crab larvae are pelagic, the estuarine plume formed by the Columbia River spilling into the ocean is spun to the north by the Coriolis force and pushed north by winter winds from the south (52, 53). Under these conditions, the Columbia River estuarine plume extends along most of the Washington coast (52-54). At the northern end of the Washington coast is a second large estuarine plume, the waters exiting the Straits of Juan de Fuca. This plume also has a semi-permanent eddy associated with it (52-54) that may mechanistically affect how many larvae are lost or retained. A bit further north, along the coast of Vancouver Island, the coastal flow is persistently to the north year-round (55). We suspect that these changes in the nearshore hydrodynamics create conditions different enough from those to the south off Oregon and California such that the recruitment dynamics of Dungeness crabs is different, but we have no idea how or if this change in hydrodynamics affects larval dispersal or delivery to the shore.

Roegner et al. (4, 56) sampled Dungeness crab megalopae during two cruises in the coastal waters off Washington and simultaneously fished light traps in two Washington estuaries, Grays Harbor and Willapa Bay. During one cruise the Columbia River estuarine plume was parallel to the coast and up against the shore and in the second, following wind-driven upwelling, the plume had moved offshore, dissipated, and recently upwelled water was adjacent to the coast. The distribution of Dungeness crab megalopae appeared to have been unaffected by the water mass change while other meroplankton were clearly affected. Light traps, sampled daily, were fished for 90 days (1 May-30 July, 1999) in both estuaries. The daily catch was pulsed, but the pulses were not related to the fortnightly tidal cycle, the winds, or whether the Columbia River plume was present or absent at the mouth of the estuaries. A light trap was fished in Coos Bay during this same period. There the catch of megalopae was also pulsed and the pulses were significantly cross-correlated to the fortnightly tidal cycle. Peak catches occurred shortly after the spring tides and the catch was >ten times larger, 14,000 in Coos Bay vs about <600 in Washington. Throughout the 23-year time series from Coos Bay, the daily samples have been cross-correlated to the spring to neap tidal cycle and, even in years with strong El Niño conditions, the catch has been larger to very much larger than what Roegner et al. (4) found in the Washington estuaries. We have no explanation for these differences.

## **Summary**

With 23 years of monitoring, our understanding of the relationship between ocean conditions, larval success and recruitment to the adult population continues to evolve. In summary; 1) The daily abundance of megalopae is pulsed and cross-correlated to the spring neap tidal cycle suggesting that the onshore transport of megalopae is due to the internal tides. 2) The annual abundance of megalopae has varied by a factor of about 3,000, from lows of around several thousand to highs of over 2.5 million megalopae caught. 3) The annual catch varies with the El Niño (lowest catches during strong El Niño conditions), PDO (more megalopae during negative PDO), the DOY of the spring transition (more megalopae with an early transition), and upwelling (more megalopae with more upwelling). 4) The annual abundance of megalopae determines the size of the four-year old age class of males, i.e., the size of the commercial catch. Our prediction of the commercial catch made four years in advance and excluding the data from marine heatwave years are on average within ±12% (SD 9%) of the observed catch. 5) The relationship between megalopae abundance and commercial catch consists of two curves, one for years with <100,000 and a second for years with >100,000 megalopae caught. Strong dependence of recruitment success on the abundance of settling megalopae may be the cause of these two curves. 6) While the annual catch of megalopae varies by a factor of 3,000, the commercial catch varies by only a factor of about 5. This also appears to be due to recruitment success varying with the abundance of megalopae, high recruitment success in low megalopae settlement years and orders of magnitude lower in high settlement years. 7) In years with marine heat wave conditions on the Oregon shelf, settling megalopae have higher recruitment success. We hypothesize that this is due to more rapid growth of the YOY crabs such that they pass through the most vulnerable small sizes more rapidly and suffer less mortality. 8) The annual catch of megalopae in Coos Bay, Oregon can be used to predict the commercial catch in California, but not Washington. The similarity between Oregon and

California is likely because variables driving the abundance of megalopae caught in Coos Bay (#3 above) are similar throughout the California Current. It is not entirely clear why a similar relationship is not observed between Coos Bay and Washington.

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**Author Contribution**

Equal contribution

**Conflict of Interest**

The authors have no conflicts of interest.

**Acknowledgements**

This work has been and continues to be critically dependent on the help from University of Oregon undergraduate students. Over the 23-year time series, somewhere around 150 undergraduates have helped with the daily sampling and enumeration of the samples. This study would have been impossible without their contributions. Drafts of this paper were reviewed by Drs. Curtis Roegner and Dave Armstrong and staff at the Oregon Department of Fish and Wildlife , Kelly Corbett, Eric Anderson and Scott Groth.

**Tables**

Table 1. Demonstration of the combined effect of the recruitment (Recruitment Index, crabs/megalopae caught) and the number of megalopae caught on the Commercial Catch. The Recruitment Index values are from Figure 8. Values were selected across the range of data and multiplied by the number of megalopae caught to get an estimate of the commercial catch in number of crabs. Note how the size of the commercial catch rises as the number of megalopae caught increases from 2,500 to 90,000 and then abruptly drops by a factor of nearly 4 with an increase in megalopae caught to 100,000.

| Annual Megalopae Catch | Recruitment Index, Crabs/Megalopae Caught | Commercial Catch, Millions of Crabs |
|---|---|---|
| 2,500 | 3,000 | 7.5 |
| 40,000 | 400 | 16 |
| 90,000 | 250 | 22.5 |
| 100,000 | 60 | 6 |
| 900,000 | 8 | 7.2 |
| 2.5 million | 6 | 14.4 |

Table 2. ΔAICcs of model selection for generalized additive model. The best fit model selected by AICc includes PDO, Spring Transition and the CUTI. Though the effects of CUTI are minimal as show by the < 2 units difference between the model with and without CUTI. PDO is the Pacific Decadal Oscillation, CUTI is the Coastal Upwelling Transport Index.

| Model | ΔAICc |
|---|---|
| PDO+Spring Transition+CUTI | 0 |
| PDO+CUTI | 6.85 |
| PDO+Spring Transition | 1.24 |
| Spring Transition+CUTI | 10.00 |
| CUTI | 14.45 |
| PDO | 9.35 |
| Spring Transition | 7.87 |

**Figure Captions**

Figure 1. Map of the West coast with A) spring/summer coastal currents and B) fall/winter coastal currents. The numbers indicate the locations of landmarks mentioned in the paper. C) Location of the light trap fished in Coos Bay, Oregon. D) Line drawing of the light trap.

Figure 2. A) 23-year time series of total annual catch of megalopae to a light trap fished in Coos Bay, Oregon. Annual catch is the summed daily catch from April through September. Strong El Niño events occurred in 1997 and 2016 when catch was lowest, 1,094 and 3,040, respectively. A gap in sampling occurred between 2001 and 2006. The annual megalopae catch appears to be bimodal and a frequency plot (B) supports this idea.

Figure 3. Sum of the monthly Oceanic Niño Index (ONI) (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). plotted with the $\log_{10}$ of the annual catch of megalopae in Coos Bay. Lowest catches occurred during strong El Niño conditions (index >15), lower catches occurred when the ENSO index was very low (<-15), and peak catches occurred when the ENSO index from between 0 and -5, essentially neutral.

Figure 4. Partial effects (left column) from best fit generalized additive models and linear regressions (right column) for the PDO phase (top row), CUTI Upwelling index (middle row) and day of the year of the spring transition (bottom row).

Figure 5. The Dungeness crabs off Oregon and California release larvae in winter. With a larval duration of 3-4 months, we should not catch megalopae after about 20 July. Larval release occurs later to the north (Washington and northward), so larvae caught late in the summer maybe from these northern populations. Enhanced southward transport due a negative PDO may lead to higher catches of these larvae. The summed PDO from August through September is plotted with the $\log_{10}$ number of megalopae caught after 20 July in Coos Bay. Using all data, the regression is not significant, however, the data point labeled with an X appears to be an outlier as it is more than two standard deviations below the regression line. Without this data point the regression is significant and the PDO index explains about 35% of the variability in late summer catches of megalopae.

Figure 6. $\text{Log}_{10}$ of the annual megalopae caught in Coos Bay plotted with the $\text{Log}_{10}$ of the commercial catch of Dungeness crabs in Oregon 4 years later. There are two significant curves, one associated with annual catches <100,000 megalopae (black squares) and a second associated with catches of megalopae >100,000 (open circles) (see supplemental material Figure 2). There were five years (1997, 2014, 2016, 2019, 2020) when there were marine heatwaves over the Oregon continental shelf during the spring and summer. These data are plotted with X's and fall well above the regression lines.

Figure 7. $\text{Log}_{10}$ calculated commercial crab catches made using the regression equations from Figure 6 and the number of megalopae caught four years prior to the fishing season against the actual $\log_{10}$ measured commercial catch in "normal" years (open circles) and in marine "heatwave" years (filled squares). The regression for the normal years is significant explaining 81% of the variability and the data fall around the 1-to-1 line (dotted line). On average, the predicted commercial catch has been within ± 12% (SD 9%) of the observed.

The five marine heatwave years also form a significant regression explaining 99% of the variability, however, there are just five data points so this should be viewed as a tentative conclusion.

Figure 8. The annual catches of megalopae are plotted against an index of recruitment success of megalopae surviving to enter the fishery as 4-year-old males. The index of recruitment success is the number of crabs landed in the Oregon fishery divided by the number of megalopae caught in the light trap in Coos Bay lagged 4 years. The relationship is formed from four clusters of points; 1 - <4,000 megalopae caught (years with strong El Niños), 2 – between 10,000 and 100,000 megalopae caught, 3 – 100,000's of megalopae caught, 4 - > 1,000,000 megalopae caught. With increasing numbers of settling megalopae, the index drops by orders of magnitude.

Figure 9. The $\log_{10}$ of the annual catch of megalopae in Coos Bay, Oregon plotted against the commercial catch of Dungeness crabs in California (A) and Washington (B) lagged 4 years. The results in A are very similar to what we present in Figure 6. The data form two significant curves, one associated with annual catches of megalopae <100,000 (open squares) and the second associated with catches >100,000 (open circles). B) There is no relationship between the number of megalopae caught in Coos Bay and the catch from coastal Washington suggesting that the variables driving the annual variation in the size of the Dungeness crab population off Washington are different from the drivers off Oregon and California. Commercial catches are plotted in C (Oregon and California) and D (Washington outer coast ports); the time series of annual catch in Oregon and California appear similar to each other and different from the time series in Washington.

# Figures

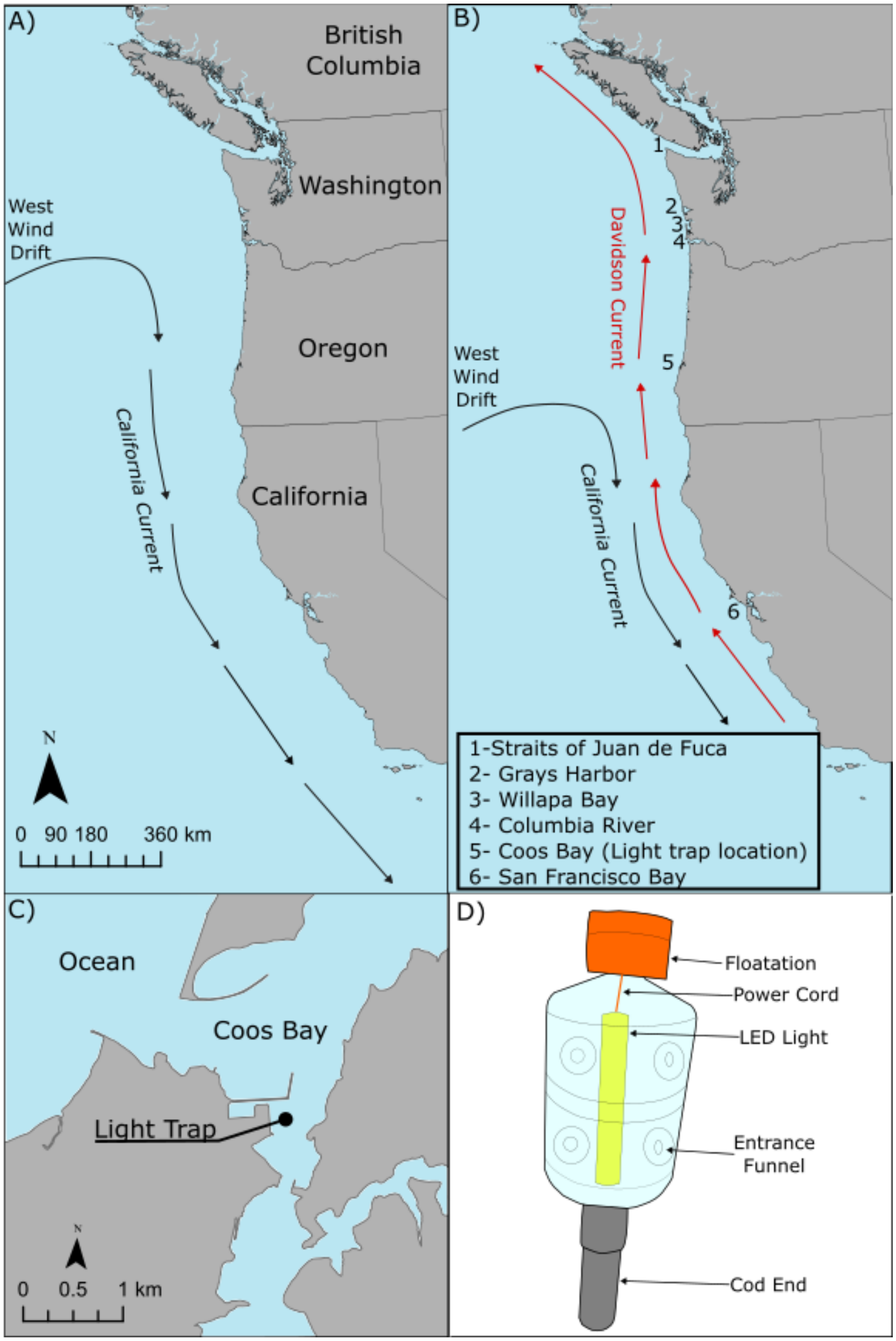
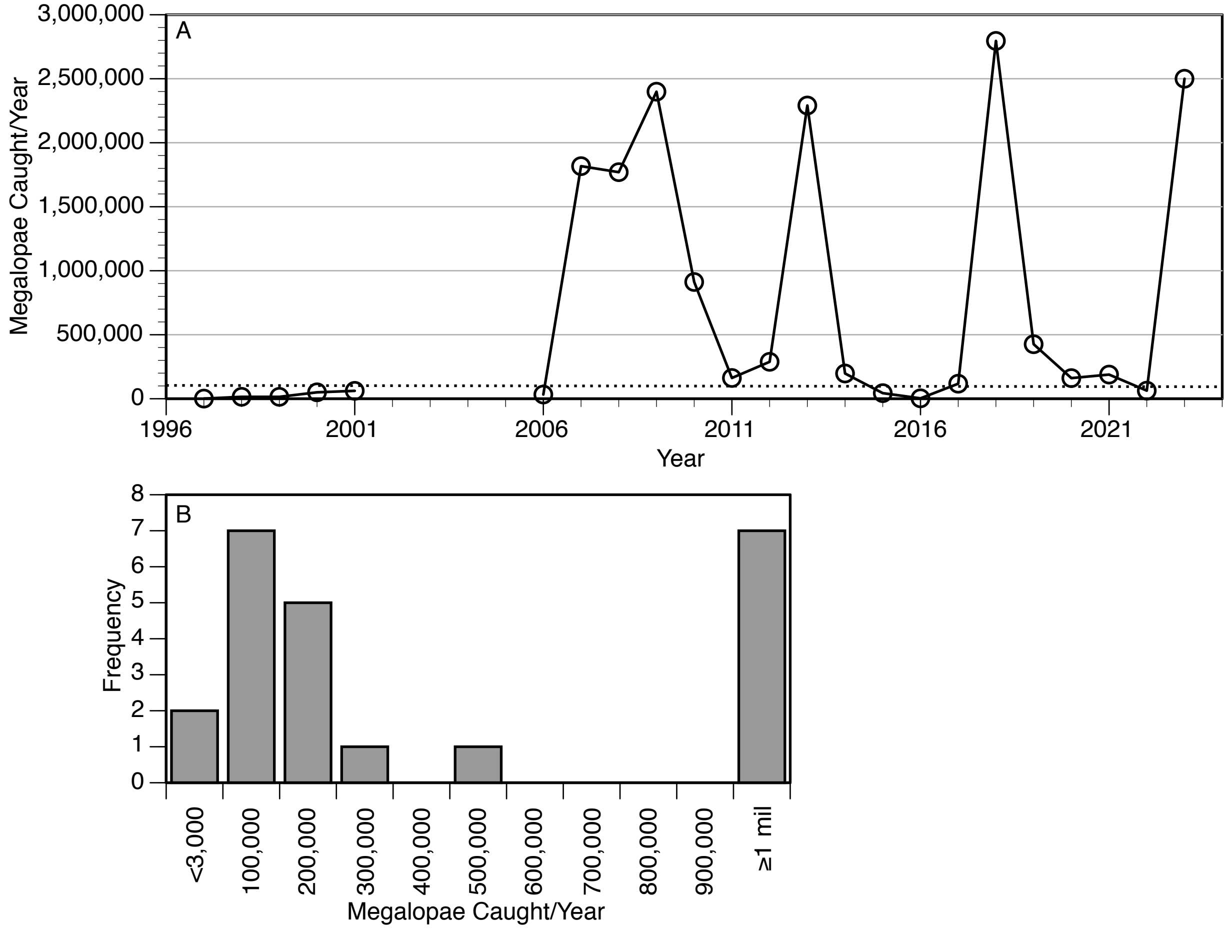



Figure 1



A
B
Megalopae Caught/Year
Year
Frequency
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1996
2001
2006
2011
2016
2021
8
7
6
5
4
3
2
1
<3,000
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
≥1 mil


Figure 2

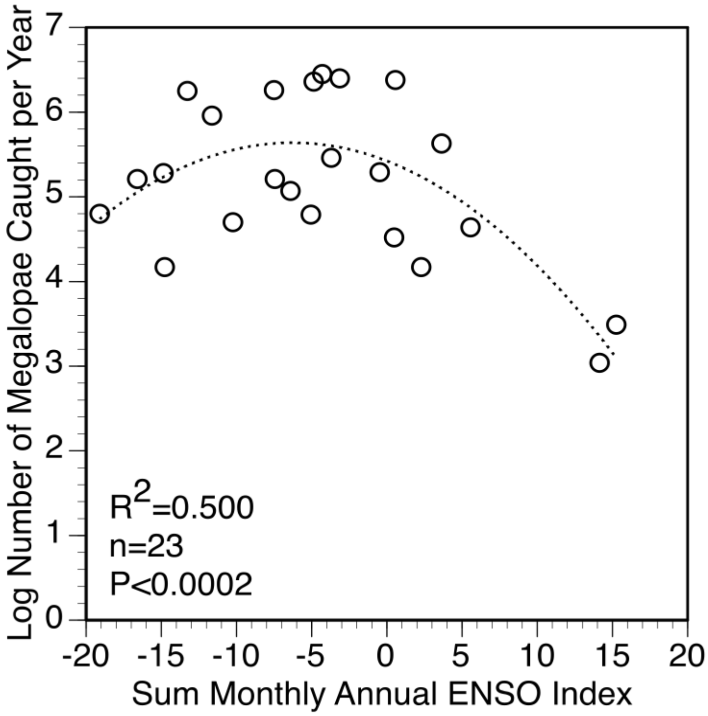

Log Number of Megalopae Caught per Year
0
1
2
3
4
5
6
7
-20
-15
-10
-5
0
5
10
15
20
Sum Monthly Annual ENSO Index
R2=0.500
n=23
P<0.0002

Figure 3

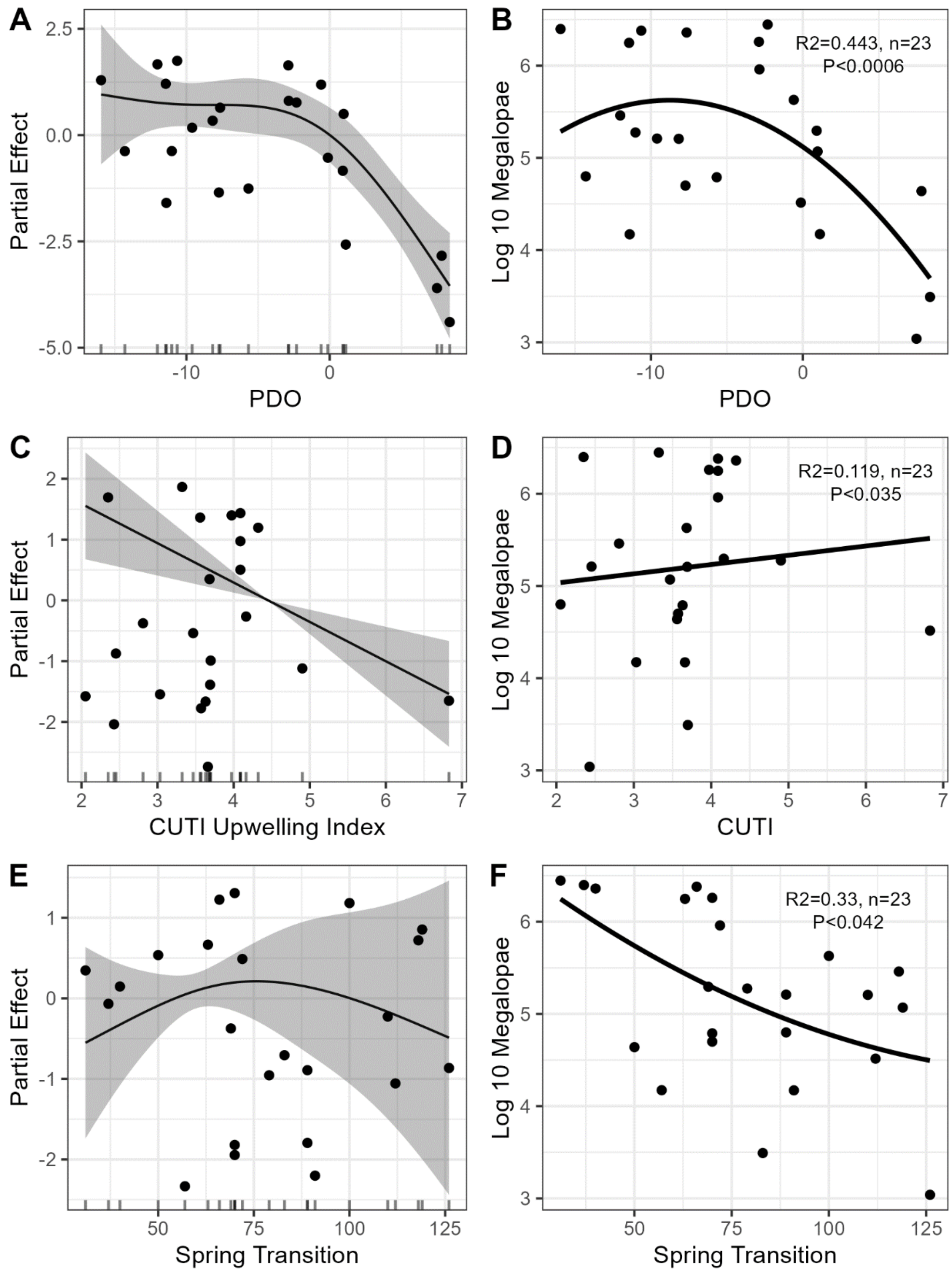

A
Partial Effect
PDO
B
Log 10 Megalopae
PDO
R2=0.443, n=23
P<0.0006
C
Partial Effect
CUTI Upwelling Index
D
Log 10 Megalopae
CUTI
R2=0.119, n=23
P<0.035
E
Partial Effect
Spring Transition
F
Log 10 Megalopae
Spring Transition
R2=0.33, n=23
P<0.042

Figure 4

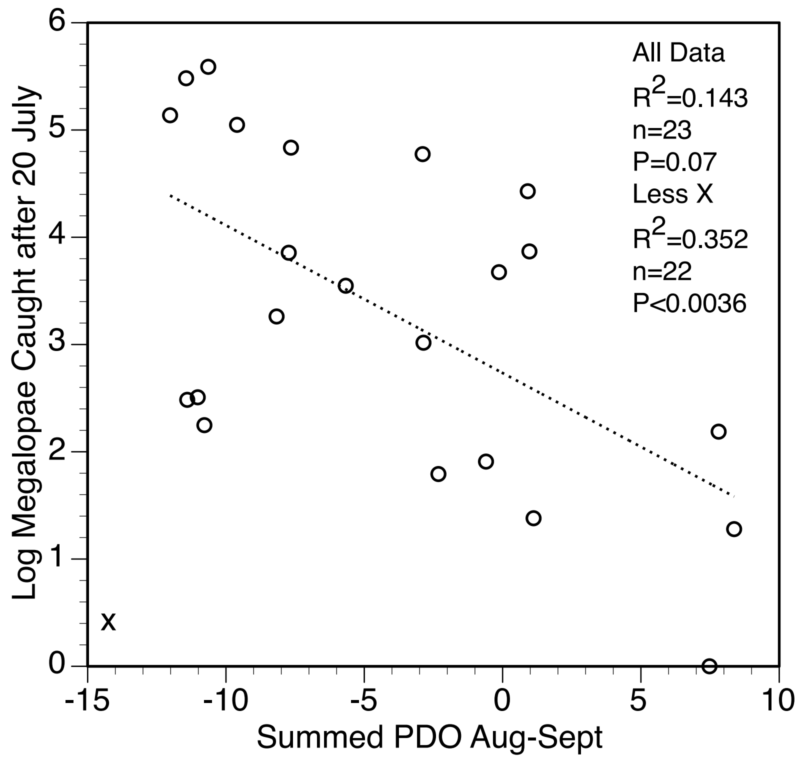
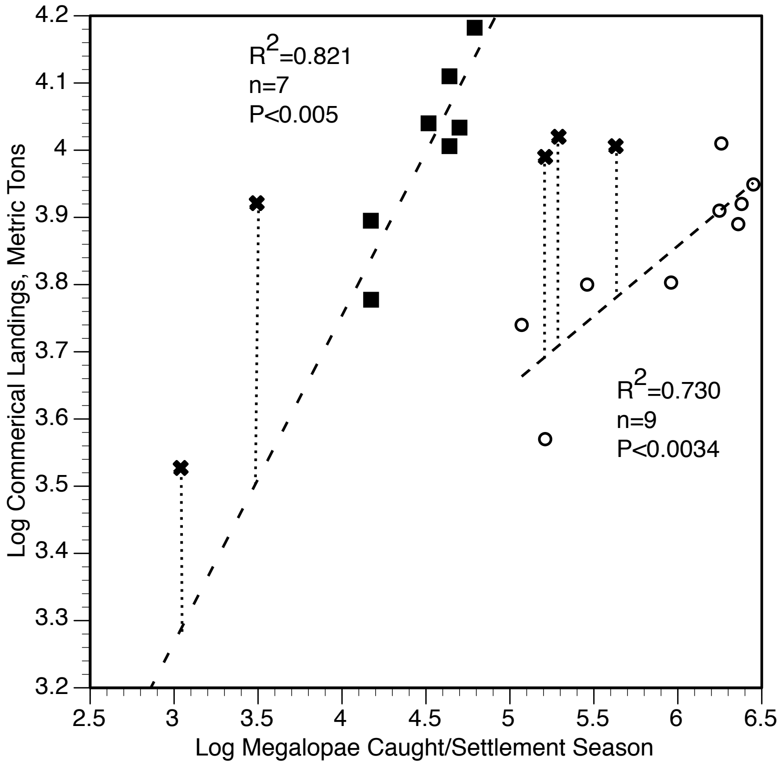
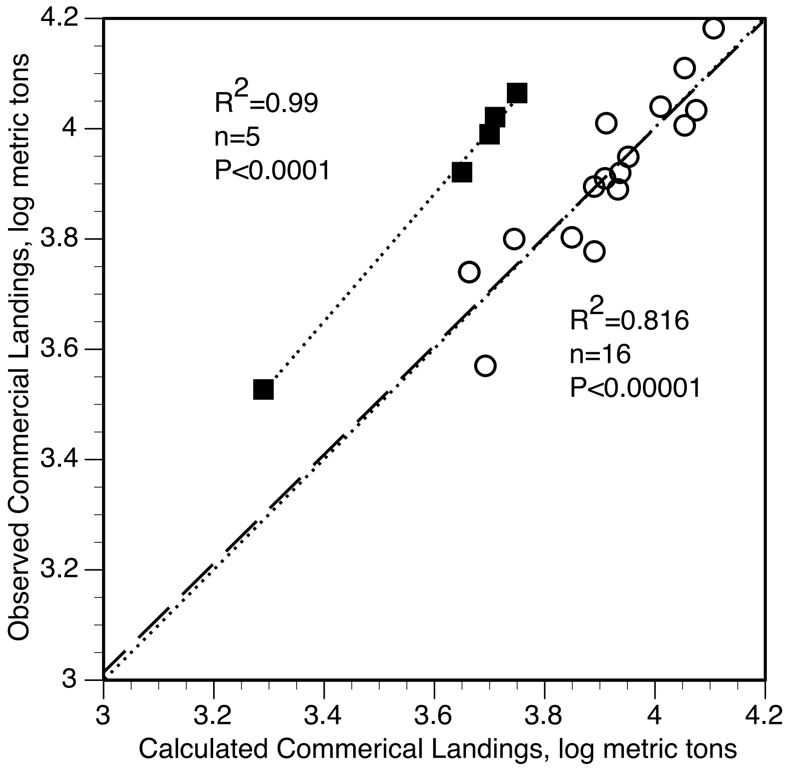

All Data
R2=0.143
n=23
P=0.07
Less X
R2=0.352
n=22
P<0.0036
X
Log Megalopae Caught after 20 July
Summed PDO Aug-Sept
0
1
2
3
4
5
6
-15
-10
-5
0
5
10

Figure 5



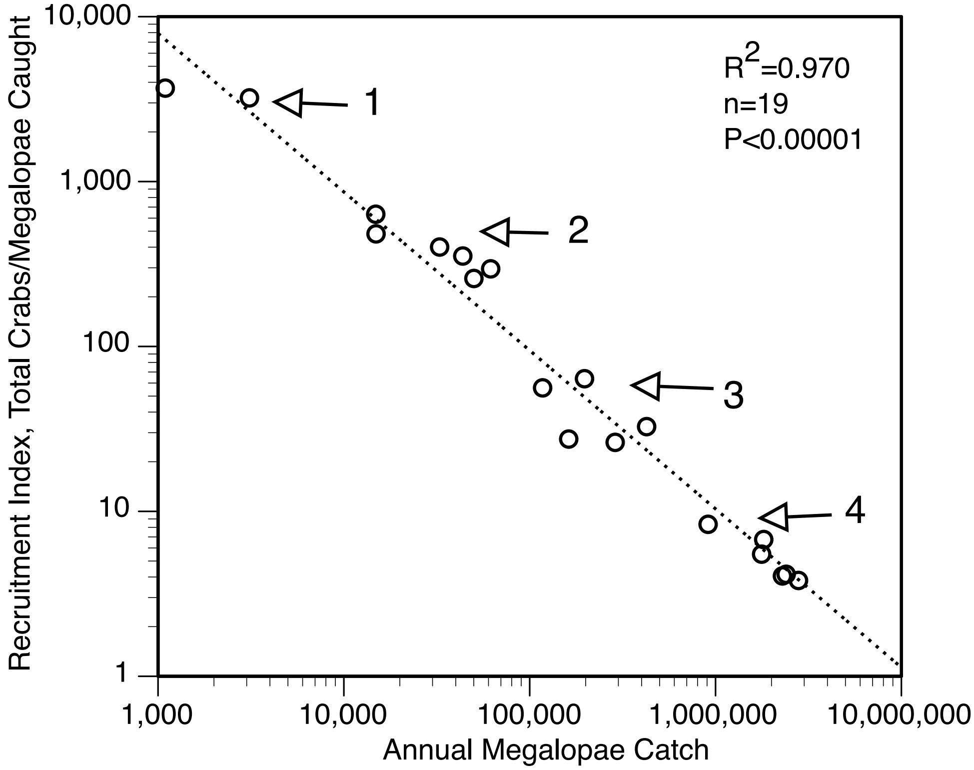
$R^2$=0.821
n=7
P<0.005
$R^2$=0.730
n=9
P<0.0034
Log Commerical Landings, Metric Tons
Log Megalopae Caught/Settlement Season
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
2.5
3
3.5
4
4.5
5
5.5
6
6.5


Figure 6



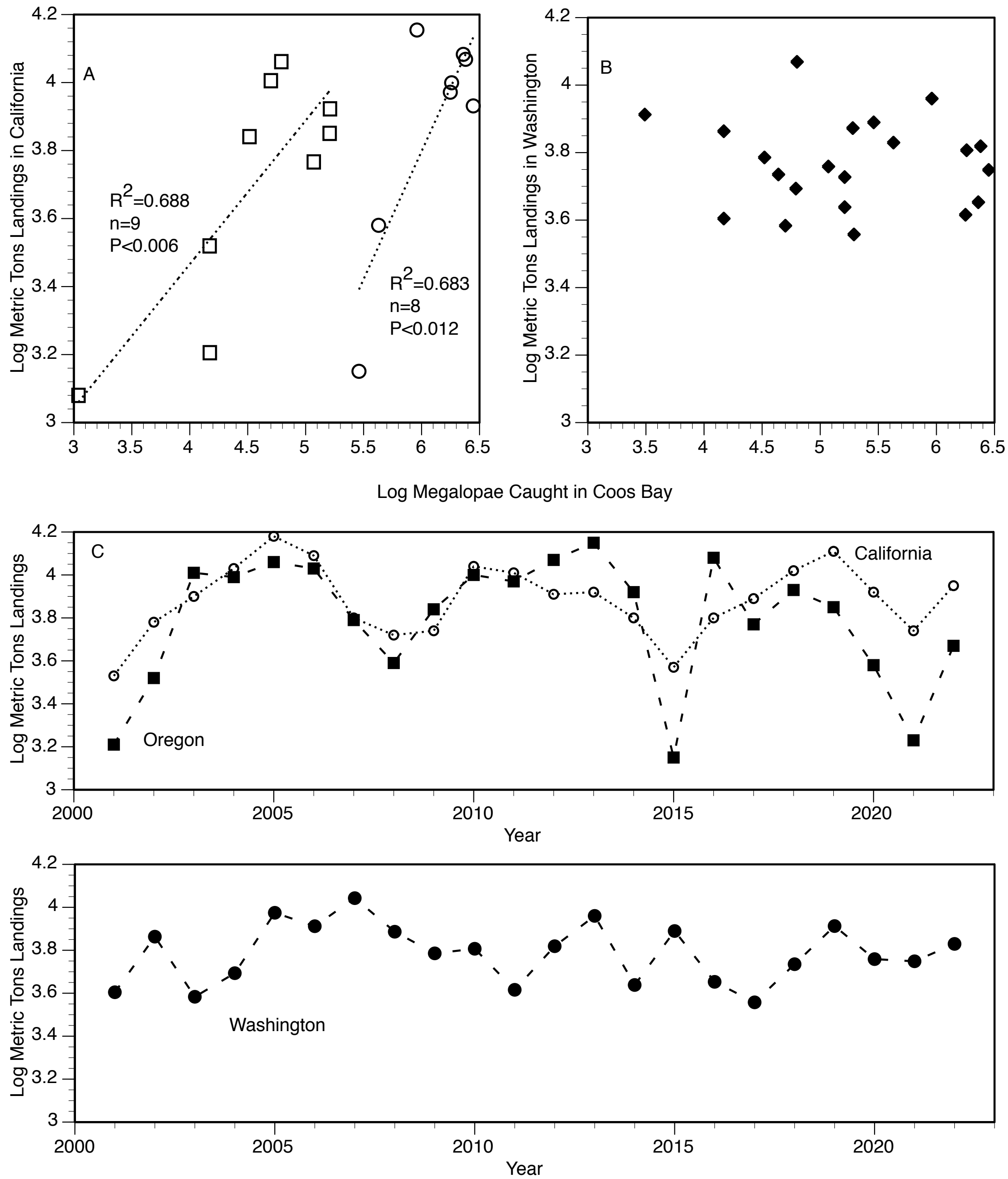
4.2
4
3.8
3.6
3.4
3.2
3
Observed Commercial Landings, log metric tons
$R^2$=0.99
n=5
P<0.0001
$R^2$=0.816
n=16
P<0.00001
3
3.2
3.4
3.6
3.8
4
4.2
Calculated Commerical Landings, log metric tons


Figure 7



Recruitment Index, Total Crabs/Megalopae Caught
Annual Megalopae Catch
10,000
1,000
100
10
1
1,000
10,000
100,000
1,000,000
10,000,000
$R^2$=0.970
n=19
P<0.00001
1
2
3
4


Figure 8

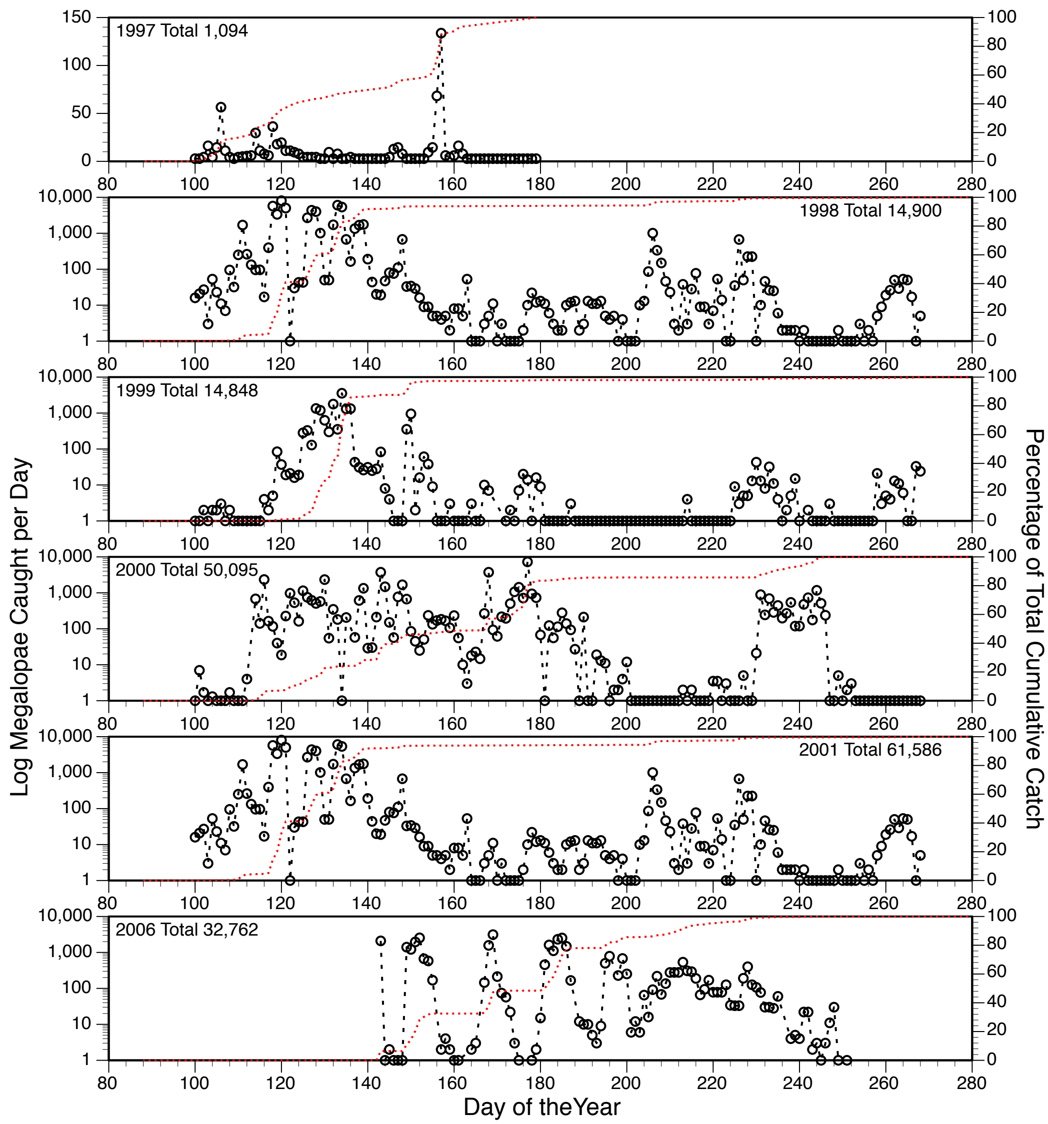


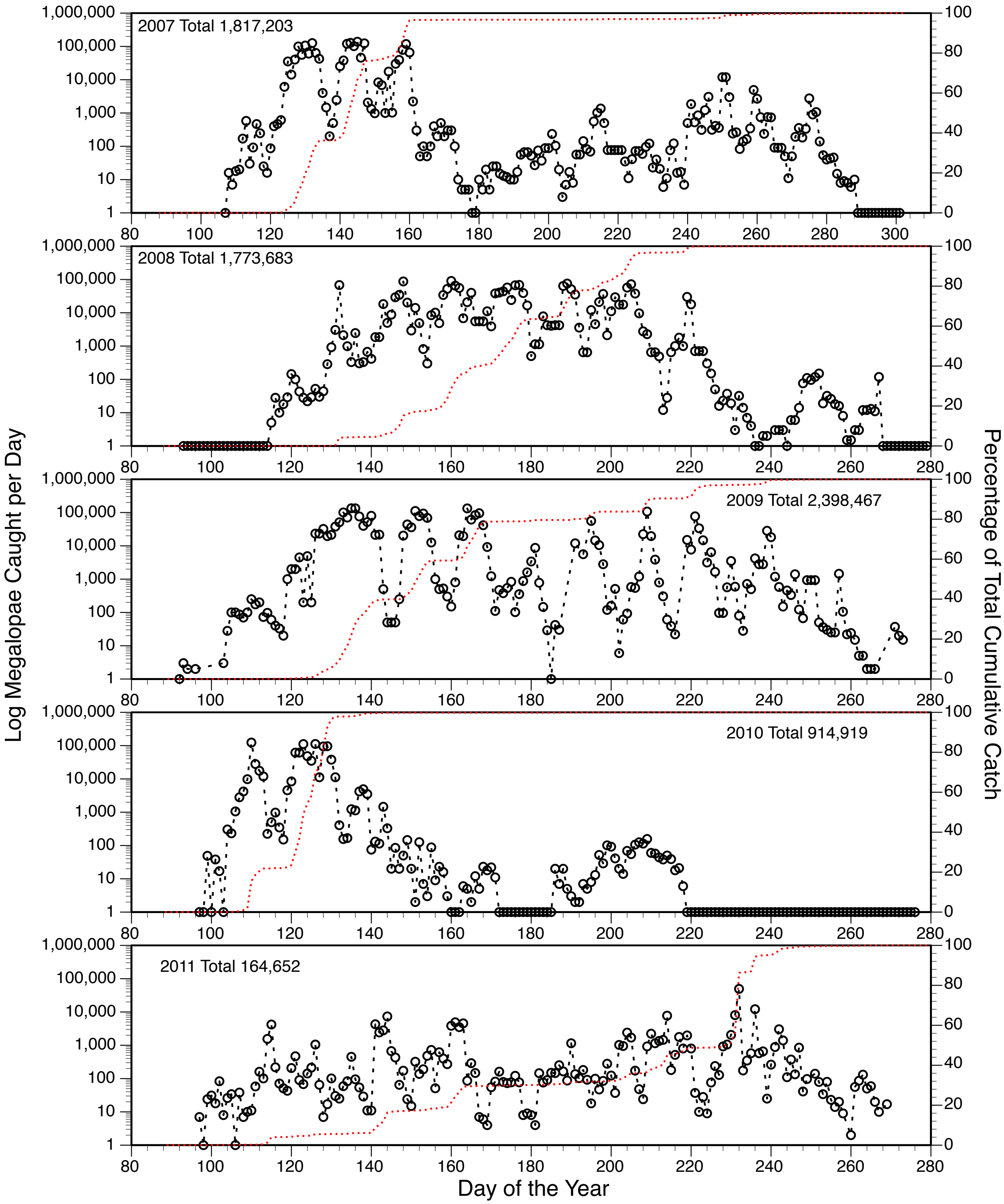
A
B
C
Log Metric Tons Landings in California
Log Metric Tons Landings in Washington
Log Metric Tons Landings
$R^2$=0.688
n=9
P<0.006
$R^2$=0.683
n=8
P<0.012
Log Megalopae Caught in Coos Bay
California
Oregon
Washington
Year

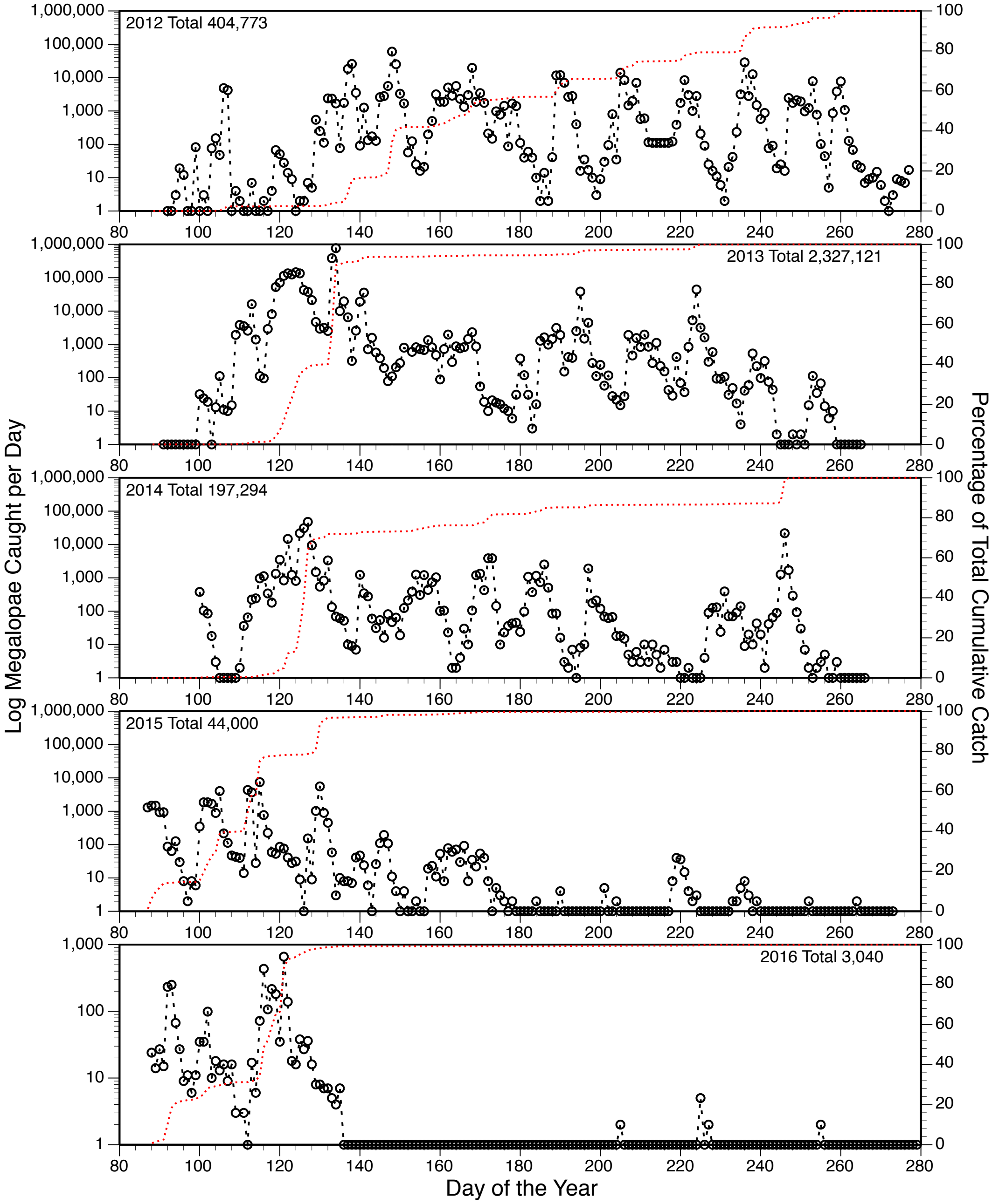

Figure 9

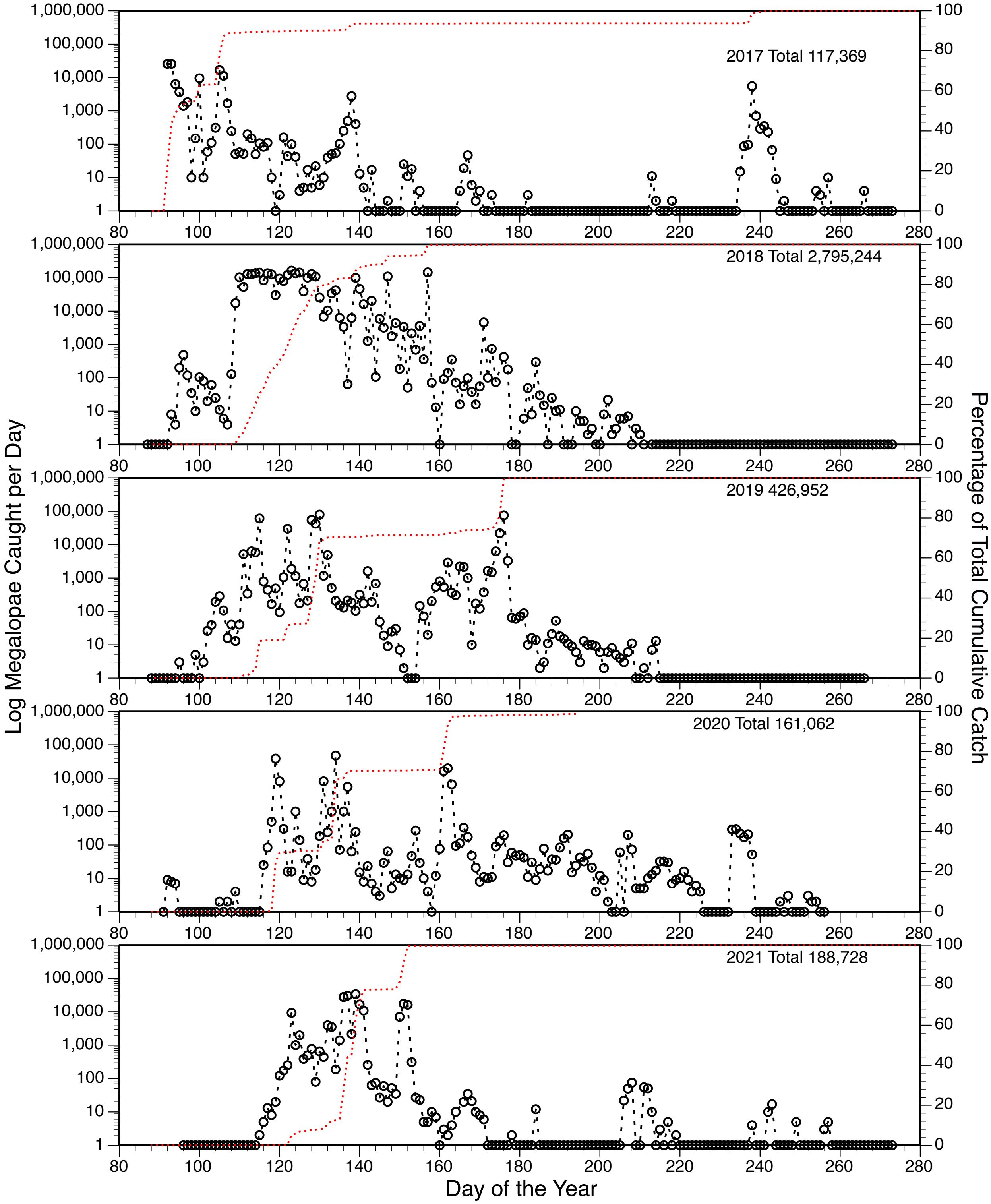
**Supplemental Material**

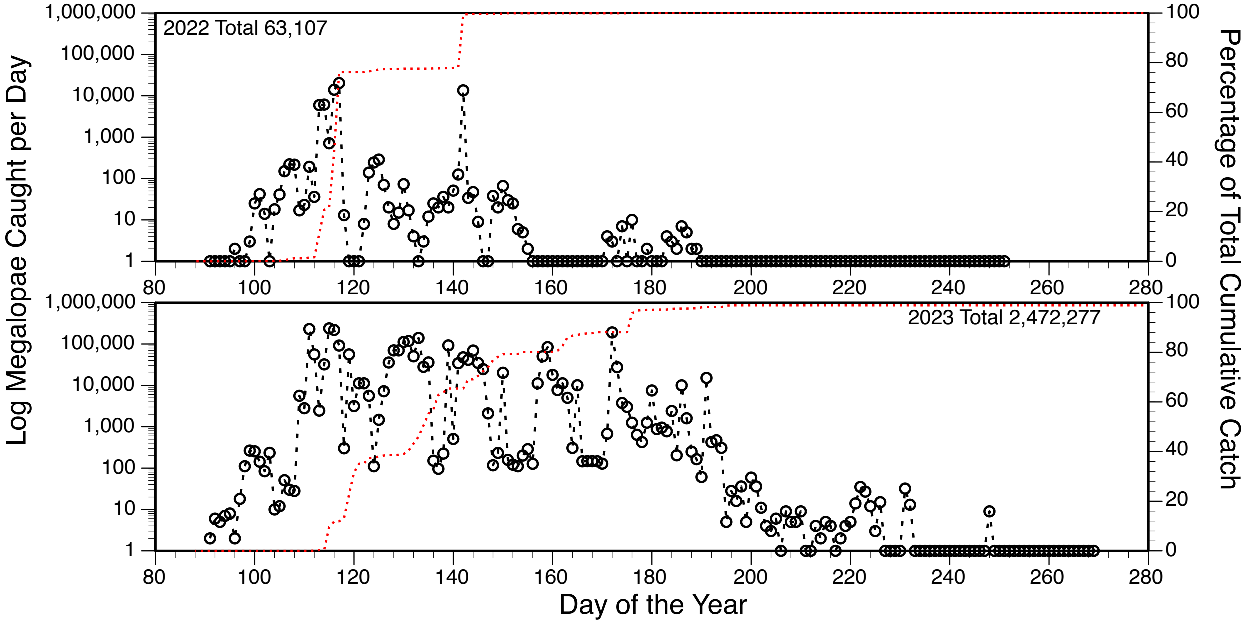
Figure 1. Daily catch of megalopae (open circles) plotted with the percentage of the cumulative catch (red dotted line). Note the changes in the scale on the left x-axis. One has been added to the daily catch to allow for plotting on a $\log_{10}$ scale. Day of the year 91=1 April and 273=30 Sept.




2007 Total 1,817,203
2008 Total 1,773,683
2009 Total 2,398,467
2010 Total 914,919
2011 Total 164,652
Log Megalopae Caught per Day
Percentage of Total Cumulative Catch
Day of the Year
1,000,000
100,000
10,000
1,000
100
10
1
80
100
120
140
160
180
200
220
240
260
280
300


2012 Total 404,773
2013 Total 2,327,121
2014 Total 197,294
2015 Total 44,000
2016 Total 3,040
Log Megalopae Caught per Day
Percentage of Total Cumulative Catch
Day of the Year
1,000,000
100,000
10,000
1,000
100
10
1
80
100
120
140
160
180
200
220
240
260
280
0
20
40
60
80
100


2017 Total 117,369
2018 Total 2,795,244
2019 426,952
2020 Total 161,062
2021 Total 188,728
Log Megalopae Caught per Day
Percentage of Total Cumulative Catch
Day of the Year
1,000,000
100,000
10,000
1,000
100
10
1
80
100
120
140
160
180
200
220
240
260
280
0
20
40
60
80
100



2022 Total 63,107
2023 Total 2,472,277
Log Megalopae Caught per Day
Percentage of Total Cumulative Catch
Day of the Year
1,000,000
100,000
10,000
1,000
100
10
1
80
100
120
140
160
180
200
220
240
260
280

Figure 2. The evolution of the relationship between the $\log_{10}$ of the number of megalopae caught and the $\log_{10}$ of the commercial catch in Oregon lagged four years. A) represents the relationship through 2006, a significant straight regression. B) extends the data one year through 2007, the first year when we caught more than a million megalopae. At this time, we thought the relationship had evolved into a parabolic curve. In C the data has been extended to 2013 and we attempted to fit a parabolic curve to the data, this was not significant. It was at this point that we realized we actually had two curves (D), one for years with catches of megalopae <100,000 and a second for years with >100,000 megalopae. Both these regressions are and continue to be significant.

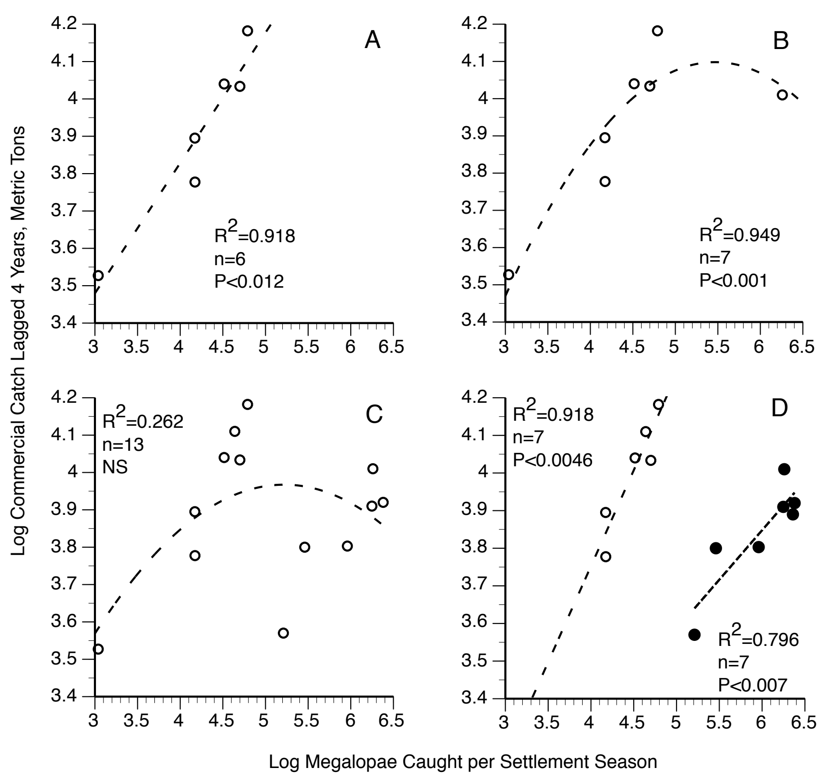


Table 1. Daily catch of megalopae in a light trap fished in Coos Bay, Oregon. Empty cells indicate no data. DOY is Julian day of the year.

| Date | DOY | 1997 | 1998 | 1999 | 2000 | 2001 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28-Mar | 87 | | | | | | | | | | | | | | | 1298 | 0 | | 0 | | | | | |
| 29-Mar | 88 | | | | | | | | | | | | | | | 1474 | 24 | | 0 | 0 | | | | |
| 30-Mar | 89 | | | | | | | | | | | | | | | 1474 | 14 | | 1 | 0 | | | | |
| 31-Mar | 90 | | | | | | | | | | | | | | | 933 | 27 | | 1 | 0 | | | | |
| 1-Apr | 91 | | | | | | | | | | | | | 0 | | 934 | 15 | | 0 | 0 | 0 | | 0 | |
| 2-Apr | 92 | | | | | | | | | 1 | | | 1 | 0 | | 87 | 233 | 25558 | 0 | 0 | 9 | | 0 | |
| 3-Apr | 93 | | | | | | | | 0 | 3 | | | 1 | 0 | | 64 | 250 | 25558 | 8 | 6 | 8 | | 0 | |
| 4-Apr | 94 | | | | | | | | 0 | 2 | | | 3 | 0 | | 126 | 67 | 6302 | 4 | 0 | 7 | | 0 | |
| 5-Apr | 95 | | | | | | | | 0 | 0 | | | 19 | 0 | | 30 | 27 | 3676 | 201 | 3 | 1 | | 1 | 1 |
| 6-Apr | 96 | | | | | | | | 0 | 2 | | 0 | 12 | 0 | | 8 | 9 | 1400 | 482 | 0 | 1 | 0 | 2 | 5 |
| 7-Apr | 97 | | | | | | | | 0 | 0 | 0 | 7 | 1 | 0 | | 2 | 11 | 1821 | 118 | 0 | 0 | 0 | 0 | 4 |
| 8-Apr | 98 | | | | | | | | 0 | 0 | | 1 | 1 | 0 | | 8 | 6 | 10 | 35 | 0 | 1 | 0 | 1 | 6 |
| 9-Apr | 99 | | | | | | | | 0 | 0 | 49 | 24 | 82 | 0 | | 6 | 11 | 149 | 10 | 5 | 0 | 0 | 3 | 7 |
| 10-Apr | 100 | 3 | 3 | 0 | 0 | 16 | | | 0 | 0 | | 31 | 1 | 32 | 378 | 348 | 35 | 9453 | 104 | 1 | 0 | 0 | 25 | 1 |
| 11-Apr | 101 | 3 | 6 | 1 | 7 | 21 | | | 0 | 0 | 38 | 18 | 3 | 24 | 104 | 1853 | 35 | 10 | 80 | 3 | 0 | 0 | 42 | 17 |
| 12-Apr | 102 | 4 | 4 | 2 | 2 | 27 | | | 0 | 0 | 17 | 83 | 1 | 19 | 85 | 1854 | 99 | 60 | 20 | 26 | 1 | 0 | 14 | 110 |
| 13-Apr | 103 | 16 | 1 | 1 | 0 | 3 | | | 0 | 3 | | 8 | 76 | 1 | 18 | 1679 | 10 | 110 | 61 | 39 | 0 | 0 | 1 | 264 |
| 14-Apr | 104 | 4 | 2 | 2 | 1 | 53 | | | 0 | 28 | 303 | 26 | 152 | 13 | 3 | 888 | 18 | 313 | 25 | 193 | 1 | 0 | 18 | 253 |
| 15-Apr | 105 | 15 | 0 | 2 | 1 | 23 | | | 0 | 100 | 232 | 34 | 48 | 112 | 1 | 4038 | 13 | 16806 | 11 | 284 | 2 | 0 | 41 | 142 |
| 16-Apr | 106 | 56 | 2 | 3 | 0 | 11 | | | 0 | 100 | 1057 | 1 | 4850 | 11 | 1 | 217 | 16 | 11204 | 6 | 107 | 1 | 0 | 150 | 83 |
| 17-Apr | 107 | 11 | 0 | 0 | 0 | 7 | | 1 | 0 | 87 | 2800 | 38 | 4200 | 10 | 0 | 113 | 9 | 1681 | 4 | 16 | 2 | 0 | 220 | 233 |
| 18-Apr | 108 | 4 | 0 | 2 | 2 | 95 | | 16 | 0 | 70 | 4200 | 7 | 1 | 15 | 1 | 47 | 16 | 244 | 129 | 40 | 1 | 0 | 216 | 9 |
| 19-Apr | 109 | 3 | 1 | 0 | 1 | 32 | | 7 | 0 | 100 | 9800 | 10 | 4 | 1932 | 1 | 43 | 3 | 51 | 17290 | 13 | 4 | 0 | 17 | 11 |
| 20-Apr | 110 | 4 | 0 | 0 | 0 | 251 | | 18 | 0 | 250 | 12355 | 11 | 2 | 3850 | 2 | 40 | 0 | 57 | 10295 | 40 | 1 | 0 | 23 | 50 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 0 | | | | | | | | 0 | | | | | |
| 21-Apr | 111 | 5 | 0 | 0 | 0 | 1690 | | 20 | 0 | 175 | 28000 | 58 | 1 | 3525 | 36 | 14 | 3 | 52 | 53006 | 5184 | 1 | 0 | 192 | 29 |
| 22-Apr | 112 | 6 | 5 | 0 | 4 | 261 | | 170 | 0 | 200 | 17500 | 160 | 1 | 2575 | 65 | 4338 | 1 | 200 | 128514 | 339 | 1 | 0 | 36 | 27 |
| 23-Apr | 113 | 6 | 1 | 0 | 0 | 133 | | 579 | 0 | 73 | 11900 | 101 | 7 | 16100 | 223 | 3674 | 17 | 149 | 126094 | 6318 | 0 | 0 | 5950 | 5600 |
| 24-Apr | 114 | 30 | 17 | 0 | 679 | 96 | | 30 | 1 | 97 | 224 | 1550 | 1 | 1400 | 242 | 28 | 6 | 50 | 136393 | 5868 | 1 | 0 | 6125 | 2800 |
| 25-Apr | 115 | 11 | 0 | 0 | 141 | 96 | | 92 | 5 | 60 | 500 | 4200 | 1 | 112 | 963 | 7465 | 72 | 106 | 141383 | 60966 | 0 | 2 | 711 | 229600 |
| 26-Apr | 116 | 8 | 1 | 4 | 2345 | 17 | | 465 | 28 | 40 | 971 | 218 | 2 | 96 | 1120 | 766 | 434 | 84 | 83214 | 792 | 25 | 5 | 14000 | 56000 |
| 27-Apr | 117 | 6 | 0 | 2 | 163 | 396 | | 246 | 10 | 33 | 348 | 71 | 1 | 2900 | 340 | 225 | 107 | 110 | 135257 | 445 | 84 | 13 | 20300 | 2450 |
| 28-Apr | 118 | 36 | 10 | 5 | 117 | 5704 | | 25 | 18 | 20 | 151 | 51 | 4 | 8050 | 180 | 59 | 216 | 10 | 125229 | 165 | 504 | 8 | 13 | 32130 |
| 29-Apr | 119 | 18 | 4 | 84 | 40 | 3355 | | 16 | 29 | 1000 | 4550 | 43 | 67 | 52500 | 1330 | 53 | 181 | 1 | 30011 | 488 | 38808 | 20 | 0 | 238700 |
| 30-Apr | 120 | 20 | 21 | 37 | 19 | 8045 | | 87 | 144 | 2000 | 8400 | 207 | 51 | 70700 | 3500 | 86 | 35 | 3 | 94403 | 95 | 8064 | 122 | 0 | 218400 |
| 1-May | 121 | 11 | 10 | 19 | 226 | 5001 | | 400 | 100 | 2000 | 61600 | 468 | 28 | 114100 | 835 | 76 | 660 | 160 | 79682 | 1058.4 | 304 | 175 | 0 | 91700 |
| 2-May | 122 | 11 | 5 | 21 | 973 | 1 | | 468 | 43 | 4500 | 61600 | 90 | 14 | 135100 | 14700 | 41 | 139 | 44 | 120956 | 30006 | 16 | 252 | 8 | 300 |
| 3-May | 123 | 9 | 2 | 16 | 532 | 30 | | 613 | 28 | 200 | 111300 | 68 | 9 | 124950 | 1225 | 28 | 18 | 99 | 162773 | 1872 | 16 | 9300 | 139 | 56000 |
| 4-May | 124 | 8 | 0 | 19 | 162 | 43 | | 6121 | 22 | 4900 | 48300 | 142 | 1 | 145600 | 808 | 31 | 16 | 42 | 135677 | 1134 | 1008 | 1000 | 244 | 3150 |
| 5-May | 125 | 4 | 46 | 282 | 1143 | 43 | | 35368 | 29 | 200 | 35000 | 213 | 2 | 134750 | 21700 | 9 | 38 | 4 | 142420 | 175 | 140 | 1975 | 287 | 11200 |
| 6-May | 126 | 4 | 477 | 328 | 752 | 2687 | | 14209 | 52 | 23300 | 112000 | 1050 | 2 | 42700 | 30800 | 1 | 27 | 5 | 38631 | 671.4 | 9 | 389 | 70 | 11200 |
| 7-May | 127 | 4 | 588 | 129 | 618 | 4358 | | 40119 | 30 | 23300 | 11200 | 65 | 7 | 37800 | 47600 | 153 | 36 | 17 | 100628 | 212 | 38 | 496 | 20 | 5600 |
| 8-May | 128 | 4 | 323 | 1340 | 508 | 4001 | | 99684 | 44 | 32200 | 94500 | 7 | 5 | 21250 | 9450 | 9 | 16 | 5 | 127576 | 55062 | 8 | 775 | 8 | 110 |
| 9-May | 129 | 3 | | 1193 | 574 | 1010 | | 55807 | 286 | 19600 | 95900 | 17 | 544 | 4700 | 1487 | 1020 | 8 | 22 | 108310 | 42606 | 18 | 80 | 15 | 1470 |
| 10-May | 130 | 3 | | 630 | 2335 | 50 | | 106053 | 922 | 21350 | 37800 | 101 | 250 | 2950 | 542 | 5551 | 8 | 6 | 25342 | 79578 | 184 | 650 | 73 | 7210 |
| 11-May | 131 | 9 | | 299 | 55 | 50 | | 60737 | 3051 | 37800 | 11200 | 30 | 112 | 3150 | 827 | 895 | 7 | 10 | 6718 | 1170 | 8064 | 445 | 17 | 35700 |
| 12-May | 132 | 3 | 57 | 1776 | 348 | 1718 | | 125982 | 68000 | 51000 | 407 | 25 | 2380 | 2525 | 3325 | 452 | 7 | 40 | 10423 | 4878 | 240 | 3950 | 4 | 70000 |
| 13-May | 133 | 8 | 2 | 353 | 182 | 6039 | | 63789 | 2123 | 100800 | 156 | 59 | 2350 | 384587 | 133 | 58 | 5 | 50 | 33790 | 504 | 1008 | 3525 | 1 | 70000 |
| 14-May | 134 | 3 | 95 | 3550 | 0 | 5362 | | 42509 | 991 | 70700 | 167 | 83 | 1680 | 766650 | 69 | 3 | 4 | 54 | 41718 | 209 | 47880 | 188 | 3 | 112000 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15-May | 135 | 3 | 106 | 1307 | 206 | 674 | | 3990 | 330 | 134400 | 1228 | 450 | 77 | 9975 | 61 | 10 | 10 | 102 | 6299 | 151 | 72 | 1400 | 12 | 117600 |
| 16-May | 136 | 4 | 815 | 1327 | 0 | 164 | | 1470 | 2454 | 133700 | 1133 | 95 | 1750 | 19600 | 52 | 8 | 0 | 252 | 3359 | 130 | 1008 | 27775 | 25 | 50400 |
| 17-May | 137 | 3 | 317 | 43 | 58 | 1347 | | 200 | 303 | 76300 | 4200 | 54 | 18200 | 6496 | 10 | 8 | 0 | 495 | 64 | 213 | 5544 | 30575 | 20 | 140000 |
| 18-May | 138 | 3 | 1675 | 31 | 615 | 1681 | | 500 | 330 | 39900 | 4900 | 29 | 25760 | 319 | 9 | 7 | 1 | 2757 | 6224 | 183 | 64 | 2175 | 36 | 28000 |
| 19-May | 139 | 3 | 3392 | 26 | 1340 | 1753 | | 2450 | 671 | 51800 | 3500 | 11 | 3500 | 2575 | 7 | 41 | 1 | 404 | 99418 | 105 | 245 | 33700 | | 35840 |
| 20-May | 140 | 3 | 921 | 31 | 29 | 191 | | 25281 | 413 | 79800 | 75 | 11 | 91 | 19137 | 1228 | 47 | 0 | 13 | 46214 | 316 | 15 | 16600 | 51 | 150 |
| 21-May | 141 | 3 | 723 | 25 | 30 | 44 | | 37877 | 1855 | 21350 | 131 | 4275 | 1260 | 35700 | 344 | 24 | 0 | 5 | 16055 | 172 | 8 | 10875 | 125 | 95 |
| 22-May | 142 | 3 | 358 | 28 | 212 | 20 | | 119614 | 1864 | 21700 | 114 | 2425 | 133 | 715 | 277 | 6 | 0 | 0 | 1260 | 1602 | 23 | 258 | 13510 | 223 |
| 23-May | 143 | 3 | 751 | 83 | 3735 | 19 | 2093 | 127579 | 18232 | 500 | 1456 | 2800 | 173 | 1577 | 60 | 1 | 0 | 17 | 20378 | 191 | 7 | 63 | 34 | 92400 |
| 24-May | 144 | 3 | 479 | 8 | 1474 | 47 | 1 | 101667 | 4981 | 50 | 329 | 7350 | 127 | 571 | 31 | 26 | 0 | 0 | 106 | 684 | 4 | 74 | 47 | 505 |
| 25-May | 145 | 4 | 115 | 4 | 151 | 80 | 2 | 137947 | 8790 | 50 | 20 | 669 | 2590 | 383 | 54 | 110 | 0 | 0 | 5829 | 49 | 3 | 27 | 9 | 34300 |
| 26-May | 146 | 13 | | 0 | 57 | 76 | 1 | 45860 | 29140 | 50 | 85 | 430 | 2800 | 196 | 16 | 194 | 0 | 0 | 3186 | 19 | 29 | 60 | 0 | 47600 |
| 27-May | 147 | 15 | 823 | 0 | 773 | 111 | 1 | 123596 | 34511 | 250 | 20 | 65 | 5600 | 79 | 81 | 108 | 0 | 2 | 108828 | 9 | 64 | 20 | 0 | 41440 |
| 28-May | 148 | 8 | 35 | 0 | 1675 | 676 | 1 | 2063 | 87256 | 20300 | 50 | 172 | 60200 | 110 | 47 | 11 | 0 | 0 | 1754 | 25 | 5 | 52 | 38 | 69440 |
| 29-May | 149 | 3 | 10 | 354 | 670 | 33 | 1401 | 1326 | 20186 | 43925 | 146 | 24 | 25200 | 206 | 64 | 4 | 0 | 0 | 4372 | 30 | 13 | 35 | 20 | 34720 |
| 30-May | 150 | 3 | 11 | 951 | 85 | 34 | 1215 | 982 | 2930 | 36050 | 20 | 15 | 3290 | 274 | 19 | 1 | 0 | 0 | 186 | 7 | 10 | 7050 | 66 | 24640 |
| 31-May | 151 | 3 | 58 | 2 | 45 | 29 | 1959 | 8351 | 14000 | 111300 | 2 | 320 | 1680 | 797 | 124 | 4 | 0 | 25 | 3359 | 2 | 9 | 17500 | 30 | 2100 |
| 1-Jun | 152 | 3 | 25 | 16 | 25 | 16 | 2544 | 6877 | 4883 | 78225 | 126 | 138 | 57 | 0 | 211 | 0 | 0 | 11 | 51 | 0 | 13 | 16275 | 25 | 116 |
| 2-Jun | 153 | 3 | 1 | 61 | 51 | 9 | 668 | 1000 | 813 | 93275 | 7 | 190 | 123 | 598 | 385 | 1 | 0 | 18 | 2149 | 0 | 47 | 310 | 6 | 232 |
| 3-Jun | 154 | 9 | 202 | 38 | 236 | 9 | 581 | 17544 | 300 | 69125 | 3 | 482 | 25 | 820 | 1247 | 2 | 0 | 0 | 692 | 0 | 270 | 27 | 5 | 20160 |
| 4-Jun | 155 | 15 | 185 | 9 | 134 | 5 | 169 | 1024 | 8465 | 12600 | 88 | 724 | 16 | 720 | 306 | 0 | 0 | 4 | 3557 | 146 | 29 | 23 | 2 | 157 |
| 5-Jun | 156 | 68 | 310 | 0 | 170 | 5 | 0 | 30000 | 10093 | 1000 | 9 | 51 | 21 | 677 | 1204 | 1 | 0 | 1 | 357 | 71 | 10 | 5 | 0 | 120 |
| 6-Jun | 157 | 134 | 312 | 0 | 184 | 4 | 2 | 39298 | 4883 | 500 | 23 | 618 | 198 | 1342 | 434 | 19 | 0 | 0 | 144248 | 20 | 4 | 5 | 0 | 110 |
| 7-Jun | 158 | 6 | 928 | 0 | 167 | 5 | 4 | 78596 | 34186 | 525 | 16 | 400 | 500 | 816 | 734 | 23 | 0 | 0 | 71 | | 1 | 10 | 0 | 200 |
| 8-Jun | 159 | 4 | 179 | 3 | 106 | 2 | 2 | 117895 | 52093 | 300 | 3 | 271 | 3150 | 479 | 1033 | 11 | 0 | 0 | 13 | 540 | 12 | 7 | 0 | 286 |
| 9-Jun | 160 | 6 | 167 | 0 | 233 | 8 | 1 | 65474 | 90186 | 150 | 0 | 3850 | 1890 | 89 | 101 | 53 | 0 | 0 | 0 | 797.4 | 77 | 0 | 0 | 126 |
| 10-Jun | 161 | 16 | 53 | 0 | 56 | 8 | 1 | 2211 | 65116 | 800 | 1 | 4900 | 1890 | 725 | 104 | 8 | 0 | 0 | 91 | 540 | 16380 | 3 | 0 | 11200 |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-Jun | 162 | 8 | 9 | 0 | 10 | 5 | 0 | 300 | 55674 | 20790 | 1 | 3500 | 5040 | 1973 | 23 | 78 | 0 | 0 | 140 | 2880 | 19908 | 2 | 0 | 50400 |
| 12-Jun | 163 | 3 | 12 | 0 | 3 | 53 | 0 | 50 | 6837 | 19600 | 6 | 4550 | 2875 | 296 | 2 | 61 | 0 | 0 | 350 | 361 | 6552 | 4 | 0 | 84000 |
| 13-Jun | 164 | 3 | 5 | 3 | 18 | 1 | 2 | 100 | 20837 | 133175 | 5 | 86 | 5600 | 872 | 2 | 71 | 0 | 1 | 71 | 306 | 94 | 10 | 0 | 17920 |
| 14-Jun | 165 | 3 | 11 | 0 | 23 | 1 | 3 | 50 | 39720 | 61425 | 2 | 290 | 2310 | 762 | 4 | 30 | 0 | 4 | 16 | 2196 | 112 | 0 | 0 | 7700 |
| 15-Jun | 166 | 3 | 23 | 0 | 15 | 1 | 0 | 100 | 5534 | 83713 | 12 | 147 | 1330 | 828 | 30 | 92 | 0 | 19 | 56 | 2142 | 329 | 20 | 0 | 11200 |
| 16-Jun | 167 | 3 | 19 | 10 | 267 | 3 | 145 | 400 | 5534 | 95495 | 5 | 7 | 3010 | 1457 | 10 | 8 | 0 | 47 | 98 | 1000 | 174 | 35 | 0 | 5000 |
| 17-Jun | 168 | 3 | 0 | 7 | 3738 | 5 | 1573 | 200 | 5534 | 41587 | 23 | 6 | 19600 | 2319 | 105 | 35 | 0 | 6 | 38 | 10 | 48 | 21 | 0 | 306 |
| 18-Jun | 169 | 3 | 0 | 0 | 93 | 11 | 3126 | 500 | 11069 | 9228 | 18 | 4 | 1890 | 864 | 1192 | 22 | 0 | 2 | 16 | 171 | 21 | 10 | 0 | 10080 |
| 19-Jun | 170 | 3 | 6 | 0 | 62 | 1 | 213 | 200 | 3906 | 1226 | 22 | 55 | 3430 | 55 | 1332 | 54 | 0 | 4 | 55 | 122 | 8 | 8 | 0 | 145 |
| 20-Jun | 171 | 3 | 6 | 0 | 216 | 3 | 74 | 300 | 38093 | 111 | 11 | 81 | 1750 | 19 | 426 | 40 | 0 | 0 | 4545 | 372.6 | 11 | 6 | 4 | 146 |
| 21-Jun | 172 | 3 | 17 | | 195 | 1 | 57 | 300 | 40372 | 471 | 1 | 161 | 211 | 10 | 3850 | 8 | 0 | 0 | 101 | 1638 | 10 | 0 | 3 | 146 |
| 22-Jun | 173 | 3 | 19 | 2 | 502 | 1 | 22 | 100 | 43953 | 379 | 0 | 79 | 147 | 21 | 3850 | 1 | 0 | 3 | 741 | 1476 | 11 | 0 | 0 | 145 |
| 23-Jun | 174 | 3 | 21 | | 1069 | 1 | 3 | 10 | 57302 | 541 | 0 | 73 | 975 | 18 | 143 | 5 | 0 | 0 | 74 | 6300 | 91 | 0 | 7 | 127 |
| 24-Jun | 175 | 3 | | 7 | 1429 | 1 | 1 | 5 | 24093 | 830 | 0 | 77 | 775 | 16 | 10 | 3 | 0 | 0 | 0 | 21888 | 131 | 0 | 1 | 676 |
| 25-Jun | 176 | 3 | 20 | 20 | 715 | 2 | 0 | 5 | 66906 | 102 | 0 | 121 | 1425 | 12 | 23 | 2 | 0 | 0 | 420 | 75654 | 193 | 0 | 10 | 190400 |
| 26-Jun | 177 | 3 | 33 | 14 | 7281 | 10 | 0 | 5 | 68697 | 355 | 0 | 77 | 87 | 10 | 36 | 0 | 0 | 0 | 177 | 3258 | 30 | 0 | 1 | 27500 |
| 27-Jun | 178 | 3 | 1 | | 938 | 22 | 1 | 1 | 39093 | 875 | 0 | 8 | 1675 | 6 | 43 | 2 | 0 | 0 | 0 | 65 | 59 | 2 | 0 | 3750 |
| 28-Jun | 179 | 3 | | 16 | 733 | 12 | 2 | 1 | 16604 | 1601 | 0 | 9 | 1400 | 31 | 45 | 0 | 0 | 0 | 1 | 60 | 48 | 0 | 2 | 3010 |
| 29-Jun | 180 | | 4 | 9 | 68 | 13 | 15 | 10 | 500 | 3385 | 0 | 8 | 110 | 377 | 24 | 0 | 0 | 0 | 0 | 70 | 50 | 1 | 0 | 1250 |
| 30-Jun | 181 | | 7 | 1 | 0 | 11 | 456 | 5 | 1135 | 8700 | 0 | 4 | 40 | 119 | 97 | 0 | 0 | 1 | 6 | 88 | 42 | 0 | 1 | 637 |
| 1-Jul | 182 | | 3 | 1 | 123 | 6 | 1613 | 20 | 1135 | 778 | 0 | 145 | 60 | 31 | 1076 | 0 | 0 | 3 | 49 | 10 | 11 | 0 | 0 | 425 |
| 2-Jul | 183 | | 2 | 0 | 56 | 3 | 1111 | 5 | 7813 | 146 | 1 | 76 | 40 | 3 | 370 | 1 | 0 | 0 | 8 | 16 | 30 | 0 | 4 | 1250 |
| 3-Jul | 184 | | 3 | 0 | 114 | 2 | 2319 | 25 | 4232 | 29 | 1 | 90 | 10 | 16 | 1152 | 2 | 0 | 0 | 295 | 14 | 9 | 12 | 3 | 7525 |
| 4-Jul | 185 | | 2 | 0 | 279 | 2 | 2522 | 25 | 4069 | 1 | 1 | 149 | 2 | 1288 | 738 | 0 | 0 | 0 | 30 | 2 | 19 | 0 | 2 | 875 |
| 5-Jul | 186 | | 1 | 0 | 140 | 10 | 1478 | 15 | 4232 | 42 | 20 | 146 | 14 | 1624 | 2508 | 0 | 0 | 0 | 15 | 3 | 78 | 1 | 7 | 950 |
| 6-Jul | 187 | | 3 | 3 | 93 | 12 | 166 | 13 | 4232 | 30 | 7 | 252 | 2 | 984 | 506 | 0 | 0 | 0 | 0 | 11 | 17 | 0 | 5 | 775 |
| 7-Jul | 188 | | 1 | 0 | 27 | 13 | 0 | 12 | 63814 | 0 | 20 | 164 | 41 | 1455 | 85 | 0 | 0 | 0 | 25 | 21 | 37 | 0 | 2 | 2400 |
| 8-Jul | 189 | | 1 | 1 | 0 | 2 | 12 | 10 | 75372 | 0 | 5 | 87 | 11640 | 3114 | 85 | 0 | 0 | 0 | 10 | 52 | 36 | 0 | 2 | 203 |
| 9-Jul | 190 | | 1 | 0 | 212 | 3 | 10 | 10 | 50953 | 0 | 3 | 1150 | 11900 | 1910 | 16 | 4 | 1 | 0 | 11 | 18 | 84 | 0 | 1 | 10000 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-Jul | 191 | | 1 | 1 | 0 | 13 | 10 | 17 | 35162 | 11900 | 2 | 136 | 7000 | 153 | 3 | 0 | 0 | 0 | 1 | 15 | 159 | 0 | 0 | 1600 |
| 11-Jul | 192 | | 1 | 0 | 0 | 11 | 5 | 56 | 3581 | 0 | 2 | 103 | 2650 | 417 | 2 | 0 | 0 | 0 | 0 | 11 | 203 | 0 | 0 | 248 |
| 12-Jul | 193 | | 0 | 1 | 19 | 11 | 3 | 66.5 | 651 | 5600 | 7 | 181 | 2800 | 396 | 7 | 0 | 0 | 0 | 0 | 9 | 15 | 0 | 0 | 163 |
| 13-Jul | 194 | | 0 | 0 | 13 | 13 | 9 | 66.5 | 651 | 0 | 5 | 92 | 399 | 2512 | 1 | 0 | 0 | 0 | 10 | 6 | 24 | 0 | 0 | 60 |
| 14-Jul | 195 | | 1 | 0 | 11 | 5 | 499 | 52 | 12046 | 55915 | 8 | 18 | 16 | 38358 | 8 | 0 | 0 | 0 | 5 | 3 | 42 | 0 | 0 | 15125 |
| 15-Jul | 196 | | 1 | 0 | 1 | 4 | 785 | 27 | 4558 | 14525 | 13 | 99 | 35 | 1492 | 10 | 0 | 0 | 0 | 5 | 13 | 32 | 0 | 0 | 423 |
| 16-Jul | 197 | | 5 | 0 | 2 | 5 | 0 | 75 | 21000 | 10500 | 52 | 47 | 17 | 4458 | 1898 | 0 | 0 | 0 | 2 | 10 | 55 | 0 | 0 | 470 |
| 17-Jul | 198 | | 1 | 0 | 2 | 1 | 228 | 37 | 36790 | 2800 | 29 | 85 | 10 | 277 | 176 | 0 | 0 | 0 | 3 | 10 | 21 | 0 | 0 | 307 |
| 18-Jul | 199 | | 2 | 0 | 4 | 4 | 678 | 88 | 2116 | 119 | 101 | 279 | 3 | 112 | 210 | 0 | 0 | 0 | 1 | 9 | 4 | 0 | 0 | 4 |
| 19-Jul | 200 | | 0 | 0 | 12 | 1 | 252 | 88 | 11069 | 158 | 92 | 123 | 9 | 243 | 119 | 0 | 0 | 0 | 1 | 6 | 12 | 0 | 0 | 27 |
| 20-Jul | 201 | | 0 | 0 | 1 | 1 | 6 | 235 | 29302 | 509 | 41 | 37 | 30 | 58 | 69 | 5 | 0 | 0 | 8 | 2 | 9 | 0 | 0 | 15 |
| 21-Jul | 202 | | 1 | 0 | 0 | 1 | 12 | 104 | 17581 | 6 | 20 | 1025 | 95 | 117 | 62 | 0 | 0 | 0 | 22 | 6 | 2 | 0 | 0 | 35 |
| 22-Jul | 203 | | 1 | 0 | 0 | 10 | 6 | 20 | 17581 | 61 | 14 | 950 | 800 | 28 | 67 | 0 | 0 | 0 | 2 | 8 | 0 | 0 | 0 | 4 |
| 23-Jul | 204 | | 1 | 0 | 0 | 13 | 65 | 3 | 56976 | 93 | 69 | 2400 | 35 | 22 | 18 | 2 | 0 | 0 | 3 | 5 | 1 | 0 | 0 | 58 |
| 24-Jul | 205 | | 0 | 0 | 0 | 86 | 16 | 7 | 71953 | 580 | 55 | 1700 | 14000 | 15 | 18 | 1 | 2 | 0 | 6 | 4 | 60 | 0 | 0 | 35 |
| 25-Jul | 206 | | 2 | 0 | 0 | 1006 | 92 | 17 | 37767 | 544 | 106 | 173 | 8400 | 28 | 15 | 0 | 1 | 0 | 6 | 3 | 1 | 22 | 0 | 10 |
| 26-Jul | 207 | | 0 | 0 | 0 | 336 | 218 | 8 | 9604 | 1201 | 125 | 48 | 1475 | 1922 | 5 | 0 | 0 | 0 | 7 | 6 | 200 | 50 | 0 | 3 |
| 27-Jul | 208 | | 0 | 0 | 0 | 149 | 68 | 56.5 | 2765 | 22400 | 114 | 24 | 2000 | 464 | 3 | 0 | 0 | 0 | 1 | 11 | 73 | 75 | 0 | 5 |
| 28-Jul | 209 | | 0 | 0 | 0 | 46 | 136 | 56.5 | 2279 | 107275 | 157 | 925 | 7000 | 1547 | 6 | 0 | 0 | 1 | 3 | 1 | 5 | 0 | 0 | 0 |
| 29-Jul | 210 | | 0 | 0 | 0 | 23 | 277 | 143 | 651 | 19600 | 60 | 2225 | 575 | 837 | 3 | 0 | 1 | 0 | 2 | 1 | 5 | 0 | 0 | 8 |
| 30-Jul | 211 | | 0 | 0 | 0 | 3 | 278 | 82 | 651 | 3850 | 57 | 1150 | 600 | 1967 | 10 | 0 | 0 | 0 | 1 | 2 | 5 | 55 | 0 | 4 |
| 31-Jul | 212 | | 0 | 0 | 1 | 2 | 278 | 69 | 488 | 792 | 44 | 1350 | 115 | 855 | 3 | 0 | 0 | 0 | 0 | 1 | 10 | 51 | 0 | 0 |
| 1-Aug | 213 | | 0 | 0 | 2 | 38 | 535 | 558 | 12 | 304 | 38 | 1450 | 111 | 276 | 10 | 0 | 0 | 11 | 0 | 7 | 13 | 10 | 0 | 0 |
| 2-Aug | 214 | | 0 | 4 | 0 | 3 | 308 | 1023 | 28 | 61 | 50 | 7750 | 111 | 1116 | 5 | 0 | 0 | 2 | 0 | 13 | 17 | 1 | 0 | 0 |
| 3-Aug | 215 | | 0 | 0 | 2 | 28 | 292 | 1364 | 651 | 39 | 39 | 180 | 111 | 225 | 2 | 0 | 1 | 0 | 0 | 1 | 32 | 3 | 1 | 0 |
| 4-Aug | 216 | | 0 | 0 | 0 | 77 | 189 | 500 | 1000 | 22 | 18 | 514 | 111 | 155 | 7 | 0 | 0 | 0 | 0 | 1 | 32 | 0 | 0 | 0 |
| 5-Aug | 217 | | 1 | 1 | 0 | 9 | 66 | 77 | 1790 | 0 | 21 | 1775 | 111 | 43 | 0 | 0 | 0 | 2 | 0 | 1 | 30 | 5 | 0 | 0 |
| 6-Aug | 218 | | 1 | 0 | 0 | 9 | 94 | 77 | 1000 | 0 | 6 | 800 | 121 | 29 | 3 | 8 | 0 | 2 | 0 | 1 | 7 | 1 | 0 | 0 |
| 7-Aug | 219 | | 2 | 0 | 1 | 3 | 169 | 77 | 29953 | 15050 | 0 | 1975 | 389 | 419 | 3 | 40 | 0 | 0 | 0 | 0 | 9 | 2 | 0 | 0 |

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| 8-Aug | 220 | | 0 | 0 | 4 | 7 | 78 | 77 | 17907 | 7700 | 0 | 800 | 1750 | 70 | 0 | 36 | 1 | 0 | 0 | 1 | 10 | 0 | 0 | 0 |
| 9-Aug | 221 | | 1 | 0 | 4 | 53 | 78 | 77 | 705 | 77000 | 0 | 37 | 8400 | 37 | 0 | 15 | 0 | 0 | 1 | 1 | 16 | 0 | 0 | 0 |
| 10-Aug | 222 | | 0 | 1 | 0 | 14 | 78 | 35 | 705 | 33600 | 0 | 10 | 3000 | 846 | 2 | 4 | 2 | 0 | 0 | 0 | 9 | 0 | 0 | 0 |
| 11-Aug | 223 | | 0 | 1 | 3 | 1 | 126 | 11 | 705 | 14700 | 0 | 28 | 1000 | 5278 | 0 | 2 | 1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 12-Aug | 224 | | 1 | 1 | 0 | 1 | 34 | 41 | 300 | 3150 | 0 | 9 | 2800 | 44345 | 0 | 3 | 5 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| 13-Aug | 225 | | 0 | 9 | 1 | 35 | 33 | 72 | 150 | 6440 | 0 | 76 | 208 | 3192 | 0 | 1 | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 14-Aug | 226 | | 0 | 3 | 1 | 671 | 33 | 72 | 50 | 1648 | 0 | 238 | 91 | 1612 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 15-Aug | 227 | | 0 | 5 | 5 | 50 | 191 | 59 | 16 | 96 | 0 | 128 | 25 | 302 | 90 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 16-Aug | 228 | | 0 | 5 | | 224 | 400 | 96 | 23 | 96 | 0 | 925 | 16 | 588 | 125 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17-Aug | 229 | | 1 | 13 | | 224 | 126 | 121 | 37 | 568 | 0 | 1050 | 11 | 94 | 130 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 18-Aug | 230 | | 0 | 43 | 21 | 1 | 107 | 23 | 19 | 3500 | 0 | 2050 | 6 | 93 | 24 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19-Aug | 231 | | 0 | 13 | 889 | 10 | 77 | 40 | 3 | 593 | 0 | 8050 | 2 | 107 | 390 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20-Aug | 232 | | 0 | 8 | 244 | 46 | 30 | 21 | 32 | 80 | 0 | 49350 | 21 | 31 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21-Aug | 233 | | 1 | 32 | 691 | 26 | 30 | 6 | 14 | 28 | 0 | 175 | 42 | 49 | 70 | 2 | 0 | 0 | 0 | 0 | 293 | 0 | 0 | 0 |
| 22-Aug | 234 | | 0 | 11 | 286 | 25 | 28 | 11 | 7 | 717 | 0 | 348 | 235 | 17 | 91 | 2 | 0 | 0 | 0 | 0 | 300 | 0 | 0 | 0 |
| 23-Aug | 235 | | 0 | 4 | 445 | 6 | 60 | 76 | 4 | 499 | 0 | 575 | 3150 | 4 | 139 | 5 | 0 | 15 | 0 | 0 | 221 | 0 | 0 | 0 |
| 24-Aug | 236 | | | 1 | 198 | 2 | 0 | 122 | 0 | 4200 | 0 | 12129.6 | 28700 | 41 | 9 | 8 | 0 | 87 | 0 | 0 | 171 | 0 | 0 | 0 |
| 25-Aug | 237 | | 0 | 2 | 269 | 2 | 0 | 16 | 0 | 2800 | 0 | 576 | 2800 | 60 | 20 | 3 | 0 | 96 | 0 | 0 | 208 | 1 | 0 | 0 |
| 26-Aug | 238 | | 0 | 5 | 542 | 2 | 4 | 17 | 2 | 2800 | 1 | 654 | 12600 | 533 | 10 | 1 | 0 | 5483 | 0 | 0 | 52 | 4 | 0 | 0 |
| 27-Aug | 239 | | 0 | 15 | 119 | 2 | 5 | 7 | 2 | 28350 | 0 | 25 | 1500 | 222 | 43 | 2 | 0 | 699 | 0 | 0 | 1 | 0 | 0 | 0 |
| 28-Aug | 240 | | 0 | 1 | 119 | 1 | 4 | 500 | 0 | 18200 | 1 | 262 | 575 | 98 | 20 | 0 | 0 | 292 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29-Aug | 241 | | 1 | 0 | 479 | 2 | 22 | 1850 | 3 | 1184 | 1 | 885 | 875 | 317 | 2 | 0 | 1 | 351 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30-Aug | 242 | | 1 | 2 | 731 | 1 | 22 | 525 | 3 | 582 | 1 | 3025 | 76 | 76 | 41 | 0 | 0 | 232 | 0 | 0 | 0 | 10 | 0 | 0 |
| 31-Aug | 243 | | 4 | 1 | 176 | 1 | 2 | 850 | 3 | 150 | 0 | 1400 | 91 | 44 | 65 | 0 | 4 | 67 | 0 | 0 | 0 | 17 | 0 | 0 |
| 1-Sep | 244 | | 0 | 1 | 1176 | 1 | 3 | 310 | 1 | 456 | 0 | 110 | 19 | 2 | 89 | 0 | 10 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2-Sep | 245 | | 0 | 0 | 512 | 1 | 1 | 1217 | 6 | 333 | 0 | 373 | 25 | 0 | 1261 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 3-Sep | 246 | | 1 | 0 | 238 | 1 | 3 | 3064 | 6 | 1400 | 0 | 134 | 16 | 0 | 21700 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 |
| 4-Sep | 247 | | 0 | 3 | | 1 | 11 | 313 | 14 | 122 | 0 | 850 | 2450 | 0 | 1699 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 5-Sep | 248 | | 0 | 0 | | 1 | 30 | 410 | 76 | 67 | 0 | 41 | 1750 | 2 | 291 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |

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| 6-Sep | 249 | | | 0 | 5 | 2 | 1 | 359 | 110 | 933 | 0 | 97 | 2100 | 0 | 93 | 1 | 0 | 0 | 0 | 1 | 0 | 5 | 0 | 0 |
| 7-Sep | 250 | | 0 | 0 | 0 | 1 | 0 | 11900 | 96 | 933 | 0 | | 1925 | 2 | 30 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 8-Sep | 251 | | 0 | 0 | 2 | 1 | 1 | 11900 | 118 | 933 | 0 | 140 | 975 | 0 | 7 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 9-Sep | 252 | | 0 | 0 | 3 | 1 | | 3000 | 150 | 50 | 0 | 79 | 1225 | 15 | 2 | 2 | 0 | 1 | 0 | 1 | 3 | 0 | | 0 |
| 10-Sep | 253 | | 0 | 0 | 0 | 1 | | 241 | 19 | 36 | 0 | 34 | 7775 | 113 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | | 0 |
| 11-Sep | 254 | | 0 | 0 | 0 | 3 | | 263 | 32 | 30 | 0 | 80 | 775 | 35 | 2 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | | 0 |
| 12-Sep | 255 | | 0 | 0 | 0 | 1 | | 83 | 26 | 25 | 0 | 23 | 101 | 68 | 3 | 0 | 2 | 3 | 0 | 0 | 1 | 0 | | 0 |
| 13-Sep | 256 | | 0 | 0 | 0 | 2 | | 141 | 18 | 25 | 1 | 14 | 44 | 14 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | | 0 |
| 14-Sep | 257 | | 0 | 0 | 0 | 1 | | 164 | 16 | 1450 | 0 | 20 | 5 | 6 | 1 | 1 | 0 | 10 | 0 | 0 | | 5 | | 0 |
| 15-Sep | 258 | | 0 | 21 | 0 | 5 | | 344 | 8 | 105 | 0 | 9 | 859 | 10 | 1 | 0 | 0 | 1 | 0 | 0 | | 0 | | 0 |
| 16-Sep | 259 | | 0 | 3 | 0 | 9 | | 4925 | 1.5 | 22 | 0 | 0 | 3850 | 0 | 3 | 0 | 1 | 1 | 0 | 0 | | 0 | | 0 |
| 17-Sep | 260 | | 4 | 5 | 0 | 19 | | 2681 | 1.5 | 24 | 0 | 2 | 7700 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 |
| 18-Sep | 261 | | 0 | 4 | 0 | 26 | | 747 | 3 | 15 | 0 | 56 | 1075 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | | 0 | | 0 |
| 19-Sep | 262 | | 0 | 13 | 0 | 50 | | 237 | 3 | 5 | | 86 | 127 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 |
| 20-Sep | 263 | | 0 | 11 | 0 | 29 | | 757 | 12 | 5 | 0 | 131 | 68 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | | 0 | | 0 |
| 21-Sep | 264 | | 0 | 6 | 0 | 53 | | 738 | 12 | 2 | 0 | 50 | 24 | 0 | 0 | 2 | 3 | 1 | 0 | 0 | | 0 | | 0 |
| 22-Sep | 265 | | 0 | 0 | 0 | 50 | | 91 | 13 | 2 | 0 | 59 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | |
| 23-Sep | 266 | | 0 | 0 | 0 | 17 | | 90 | 11 | 2 | 0 | 20 | 7 | | 0 | 0 | 2 | 4 | 0 | 0 | | 0 | | |
| 24-Sep | 267 | | 0 | 33 | 0 | 1 | | 90 | 118 | 0 | 0 | 10 | 9 | | | 0 | 0 | 0 | 0 | | | 0 | | |
| 25-Sep | 268 | | 0 | 24 | 0 | 5 | | 50 | 0 | 0 | 0 | | 10 | | | 0 | 0 | 1 | 0 | | | 0 | | |
| 26-Sep | 269 | | | | | | | 11 | 0 | 0 | 0 | 17 | 15 | | | 0 | 1 | 0 | 0 | | | 0 | | |
| 27-Sep | 270 | | | | | | | 50 | 0 | 0 | 0 | | 6 | | | 0 | 0 | 0 | 0 | | | 0 | | |
| 28-Sep | 271 | | | | | | | 192 | 0 | 37 | 0 | | 2 | | | 0 | 0 | 0 | 0 | | | 0 | | |
| 29-Sep | 272 | | | | | | | 355 | 0 | 20 | 0 | | 1 | | | 0 | 0 | 0 | 0 | | | 0 | | |
| 30-Sep | 273 | | | | | | | 183 | 0 | 15 | 0 | | 3 | | | 0 | 2 | 0 | 0 | | | 0 | | |
| 1-Oct | 274 | | | | | | | 334 | 0 | | 0 | | 9 | | | | 0 | | | | | | | |

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| 2-Oct | 275 | | | | | | | 2750 | 0 | | 0 | | 8 | | | | 0 | | | | | | | |
| 3-Oct | 276 | | | | | | | 901 | 0 | | 0 | | 7 | | | | 0 | | | | | | | |
| 4-Oct | 277 | | | | | | | 1066 | 1 | | | | 17 | | | | 0 | | | | | | | |
| 5-Oct | 278 | | | | | | | 139 | 0 | | | | | | | | 0 | | | | | | | |
| 6-Oct | 279 | | | | | | | 54 | 0 | | | | | | | | 0 | | | | | | | |
| 7-Oct | 280 | | | | | | | 40 | 0 | | | | | | | | 0 | | | | | | | |
| 8-Oct | 281 | | | | | | | 43 | 0 | | | | | | | | 0 | | | | | | | |
| 9-Oct | 282 | | | | | | | 46 | 0 | | | | | | | | 0 | | | | | | | |
| 10-Oct | 283 | | | | | | | 15 | 0 | | | | | | | | 0 | | | | | | | |
| 11-Oct | 284 | | | | | | | 8 | 0 | | | | | | | | 0 | | | | | | | |
| 12-Oct | 285 | | | | | | | 9 | 0 | | | | | | | | 0 | | | | | | | |
| 13-Oct | 286 | | | | | | | 8 | 0 | | | | | | | | 0 | | | | | | | |
| 14-Oct | 287 | | | | | | | 6 | 0 | | | | | | | | 0 | | | | | | | |
| 15-Oct | 288 | | | | | | | 10 | 0 | | | | | | | | 0 | | | | | | | |
| 16-Oct | 289 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 17-Oct | 290 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 18-Oct | 291 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 19-Oct | 292 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 20-Oct | 293 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 21-Oct | 294 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 22-Oct | 295 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 23-Oct | 296 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 24-Oct | 297 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25-Oct | 298 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 26-Oct | 299 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 27-Oct | 300 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 28-Oct | 301 | | | | | | | 1 | 0 | | | | | | | | 0 | | | | | | | |
| 29-Oct | 302 | | | | | | | | 0 | | | | | | | | 0 | | | | | | | |
| 30-Oct | | | | | | | | | 0 | | | | | | | | | | | | | | | |

Table 2 **.** Summary of best fit generalized additive model (GAM) from the mgcv package in R. Model was fit using a Tweedie distribution and the model selection was conducted using a backwards AICc approach. edf- effective degrees of freedom, Ref.df- Reference degrees of freedom

Family: Tweedie(p=1.99)
Link function: log

Formula:
Megalopae ~ s(PDO, k = 5) + s(ST, k = 5) + s(CUTI, k = 5)

**Parametric coefficients:**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 12.5230 | 0.2302 | 54.41 | <2e-16 |

**Approximate significance of smooth terms:**

| | edf | | Ref.df | F-value | p-value |
|---|---|---|---|---|---|
| s(PDO) | 2.540 | 3.017 | | 10.946 | 0.000302 |
| s(ST) | 1.000 | 1.000 | | 12.028 | 0.002939 |
| s(CUTI) | 1.571 | 1.886 | 0.611 | | 0.491579 |

$R^2$(adj) = 0.628    Deviance explained = 63.1%
-REML = 316.3    Scale est. = 1.3809    n = 23

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