Report on the Recruitment of Dungeness Crab Megalopae During the 2017 Recruitment Season

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Light trap sampling began on 2 April 2017 with a trap placed near the end of F dock in the Charleston Outer Boat Basin. Daily sampling continued through 30 September 2017. Total catch of Dungeness crab megalopae for the recruitment season was 117,359 (Figure 1).

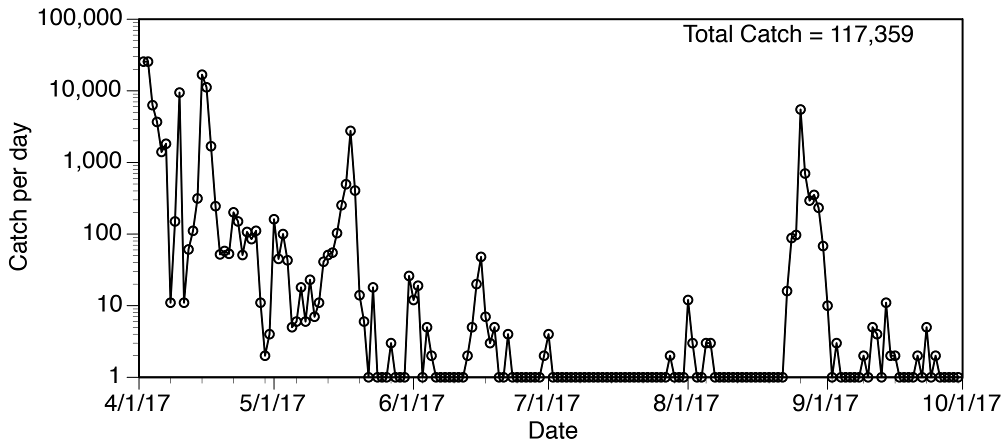

Figure 1. Daily catch of Dungeness crab megalopae in a light trap fished from F Dock in Charleston Harbor during spring, summer and early fall of 2017.

Over the 17 years of sampling the number of returning megalopae has varied from 2,000 to 2.4 million megalopae. The years appear to fall into two groups, years with < 100,00 (low) and >100,000 (high) returning megalopae (Figure 2). Whether a year's catch is low or high appears to depend initially on the phase of the Pacific Decadal Oscillation (PDO) and whether there is a strong El Niño occurring. When the index is positive or there is a strong El Niño, catches tend to be low as was the case in 2016 (strong El Niño), and the reverse when the index is negative (Figure 3A). Dungeness crabs in Northern California and Oregon release larvae in winter (January through February, maybe into March) and the larval period is three to four months, hence, after July we should not catch anymore megalopae, but, as you can see in Figure 1, we catch megalopae into the fall. Off Vancouver Island and northward, larval release occurs in spring and summer; the megalopae we catch in late summer and fall in Coos Bay are likely from this source. If this is true then we would expect to see more megalopae caught late in the season when the PDO index is negative and more water is flowing southward in the California Current. In Figure 3B I have plotted the PDO index and the late season catch of megalopae; there is a significant correlation between the two variables. This result is consistent with the hypothesis that during years with negative PDOs more water travels south in the California Current transporting megalopae southward and leading to higher catches of megalopae in Oregon. During this past year there was a weak La Niña and the PDO index was weakly positive and the catch of megalopae was relatively low consistent with these index values.

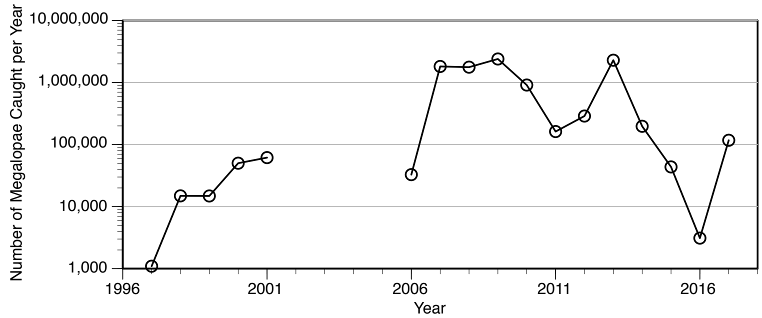

Figure 2. The annual catch of megalopae during the 17 years of study. During the first six years, catches were all < 100,000, between 2007 and 2014 catches have been > 100,000. In 2015, the year of the 'warm blob', catch dropped down to 44,000 and in 2016, a year with a strong El Niño, catch was only 3,106 comparable to the catch during the last strong El Niño in 1997/1998. Catch in 2017 has again risen to about 100,000, however, just slightly.

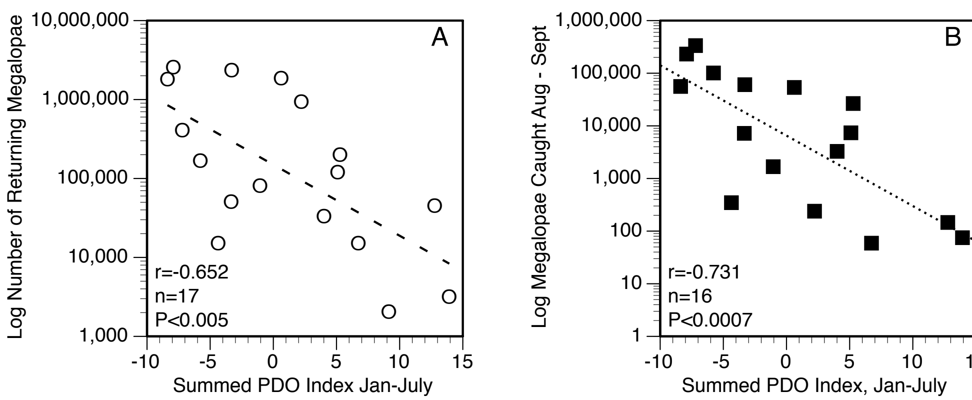

Figure 3. A) Relationship between the summed monthly PDO index from January through July and the log number of megalopae caught per season. The dashed line and statistics are the result of a regression run between the two factors. About >43% of the variability in the annual catch of megalopae is explained by the PDO index. B) PDO index summed for the months of January through July plotted with the log number of megalopae caught in August and September. The PDO index explains about 53% of the variability in the late season catch of megalopae.

In Figure 4 I have plotted the day of the year of the spring transition against the number of megalopae caught. The spring transition occurs when the winter winds from the south shift to the spring/summer winds from the north at which time the upwelling season begins. The catch data have been split into two groups, years with <100,00 megalopae caught and years with >100,000 megalopae caught. 2017 falls into the second group, but just barely. The relationship between catch and the day of the year of the spring transition remains significant; the earlier the spring transitions the more megalopae are caught in both types of years.

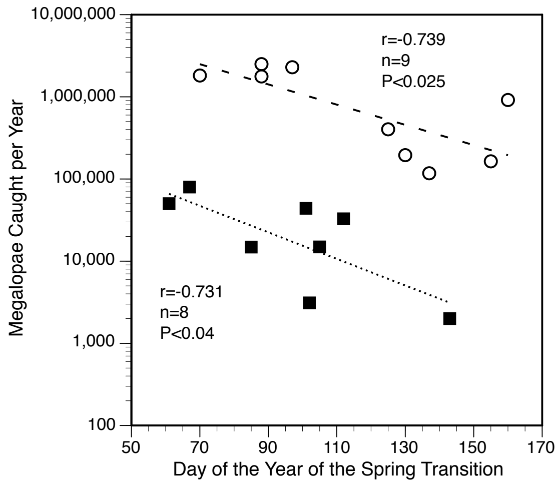

Figure 4. Day of the year of the spring transition plotted with the annual catch of megalopae. The catch data have been divided into years with low catch (<100,000 caught, filled squares) and high catch (>100,000 caught, open circles). The dotted lines and statistical results are from regressions run between the variables.

Last year I realized that the relationship between the number of megalopae caught and the size of the commercial catch four years later is made up of two curves, years with low (<100,000) and high (>100,000) returning megalopae (Figure 5). I am not sure why this relationship takes the form of two curves. The relationship suggests that something different is happening post-settlement during years with high to very high returns of megalopae (i.e., when >100,000 megalopae return).

Given the number of megalopae caught in 2014 (197,394), I predicted that the commercial landings for the 2017/2018 season should be around 10,000,000 lb. and it looks like the total landing will be more on the order of 23,000,000 lb. My estimate is way way off (X symbol in Figure 5), which is fascinating as this is the first year where my estimated landings have been so far off. What might have caused this disparity? Starting in 2013 due to climate change dynamics (*1*), the water in the Eastern North Pacific warmed substantially. This was due to a persistent high-pressure ridge that formed in the northern North Pacific, which blocked storms moving across the Eastern North Pacific (*2*). This decreased mixing allowing a huge mass of water to warm up; this was dubbed the 'warm blob'. The blob persisted into 2016 and in spring/summer 2014 moved from the open ocean onto the shelf. Average high tide (i.e., coastal ocean water) seawater temperatures in winter 2015 measured at the OIMB pier near the mouth of Coos Bay were around 12 ºC compared to a normal winter when temperatures average around 10 ºC. In 2016 there was a major El Niño and the water was again warmer than average by at least 1 ºC. All else being equal, coldblooded animals, like crabs, tend to grow faster when conditions are warmer. Under warmer conditions, perhaps megalopae that settled in spring/summer 2015 reached market size in three rather than the typical four years. If this were the case, then the landings for the 2017/2018 commercial season would be due to crabs that returned in 2014 augmented by crabs that returned in 2015. The flip side of this speculation is that the commercial catch next year may be lower than my estimate because some portion of the crabs that settled in 2015 had already reached market size.

With the current available data we cannot test this hypothesis. If true it would appear to be a rare event (i.e., two very warm years in a row), however, meteorologists have determined that the 'warm blob' was very likely due to anthropogenic affects on climate (*1*) – global climate change. Under normal conditions they estimate that a warm blob event would occur once in every 125 years, a rare event, but under climate change conditions, they estimate that warm blobs may occur in 1 in 5 years, not a rare event. The only way to test the hypothesis that crabs settling in 2015 grew to market size in 3 years is to run growth experiments at different temperatures. In addition, we could see this type of accelerated growth by following the actual pattern of recruitment of crabs once they have settled into the bottom population.

As explained above, I think the relationship between the number of megalopae caught in 2014 and the subsequent commercial landings this year is aberrant due to the unique environmental conditions of the warm blob followed by a strong El Niño; I have excluded this data point from my calculations. The data point should go with the line for years with >100,000 megalopae caught (filled circles, Figure 5), but is clearly way off this line. If I use the data point in this relationship the correlation in not significant. I can use the equations from the regressions in Figure 5, ignoring the most recent data point (the X in Figure 5) to calculate the expected commercial landings. These results are presented in Table 1.

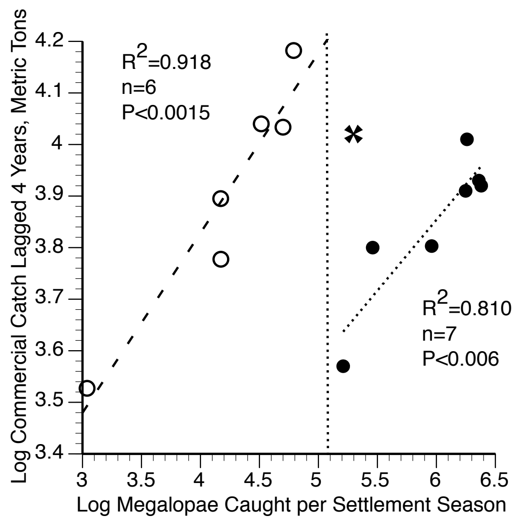

Figure 5. Log of the total number of *C. magister* megalopae caught per settlement season plotted against the log of the commercial landings lagged four years with years with catches < and > 100,000 (open and filled circles, respectively) plotted separately. The Oregon landings data are up to date (commercial landings for 2017/2018 were estimated from the catch through February). The X indicates the data point for this year, which relates the 2014 megalopae return to the landings in the 2017/2018 fishing season. Note that this data point falls between the two curves and I have not used it in the subsequent statistics nor have I used it to calculate the future commercial landings. In 2017 117,359 megalopae were caught. Should the equation associated with the filled or open circles be used to calculate the future commercial catch for these data? I am not sure; we do not have enough data yet. I have placed a vertical dotted line at 5.07 (log of 117,359) and where it crosses the two regression lines is the modeled future commercial landing. I have included both estimates in Table 1; the 2020/2021 fishing season will either be mediocre or large.

Table 1. Predicted Oregon commercial catch of Dungeness crab for fishing years 2018/2019, 2019/2020, and 2020/2021. As described in the text, the 2017 return of megalopae could lead to poor or great commercial landing and I have calculated the estimated landings using both regression equations from Figure 5. The equations relating low and high megalopae catches to commercial landings are Log metric tons of landing= 0.388807(log megalopae caught)+2.432948 and Log metric tons of landing=0.2744752(log megalopae caught)+2.206959, respectively.

Recruitment Year	Log Number of Megalopae Caught	Commercial Fishing Year	Estimated Commercial Landings, lbs
2015	4.64	2018/2019	24,730,100
2016	3.49	2019/2020	8,446,214
2017	5.07	2020/2021	8,729,129 or 35,010,300

References

1. E. C. Oliver, S. E. Perkins-Kirkpatrick, N. J. Holbrook, N. L. Bindoff, 9. Antrhopogenic and natural influences on record 2016 marine heat waves. *Bulletin of the American Meteorological Society, Special Report*, S44-S48 (2018).
2. N. A. Bond, M. F. Cronin, H. Freeland, N. Mantua, Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophysical Research Letters* **42**, 3114-3420 (2015).