Report on the Recruitment of Dungeness Crab Megalopae During the 2022 Recruitment Season

Dr. Alan Shanks
Oregon Inst. of Marine Biology
University of Oregon

Light trap sampling began on 1 April 2022 with a trap placed near the end of F dock in the Charleston Outer Boat Basin. Daily sampling continued through 30 September 2021. Total catch of Dungeness crab megalopae for the recruitment season was 63,079 (Figure 1). Peak catches of megalopae began in late April and continued through May after which catch dropped off dramatically; after the first week in July, catch was zero for the remainder of the recruitment season.

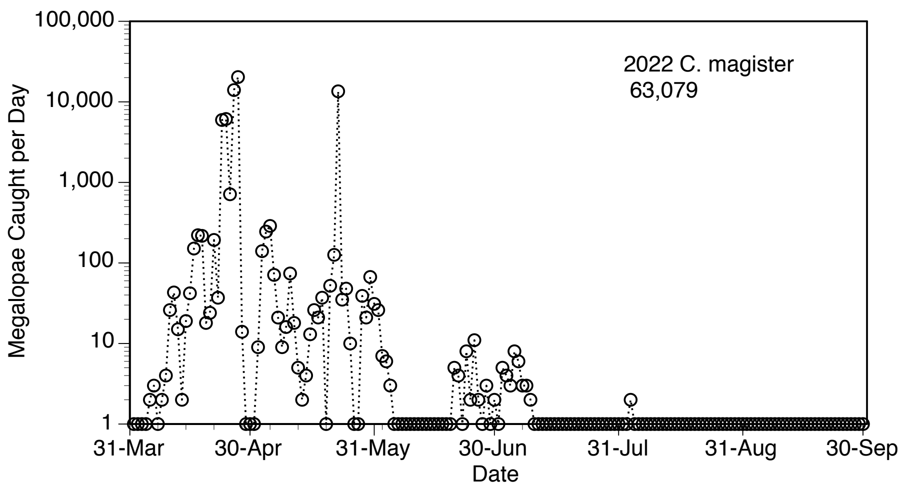

Figure 1. Daily catch of Dungeness crab megalopae in a light trap fished from F Dock in Charleston Harbor during spring, summer and early fall of 2022. To plot the data on a log scale one has been added to each daily count.

Over the 20 years of sampling the number of returning megalopae has varied from 2,000 to 2.8 million megalopae. The years appear to fall into two groups, years with < 100,00 (low) and >100,000 (high) numbers of returning megalopae (Figure 2). Whether a year's catch is low or high appears to depend initially, at least in part, on the phase of the Pacific Decadal Oscillation (PDO) and whether there is a strong El Niño occurring. When the PDO index is positive (California Current water is warmer) 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 PDO index is negative (California Current water is cooler, Figure 3A). This relationship explains about 33% of the variability

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 in most years we catch megalopae in August and September. Off Vancouver Island and northward and in Puget Sound and the Salish Sea, larval release occurs in spring and summer; the megalopae we catch in late summer and fall in Coos Bay are likely from these sources. 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. Up until last year there was a significant correlation between the two variables. This result was 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 the last couple of years this relationship has degraded and the regression is no longer significant. Current with this loss of significance has been a string of marine heat waves (heat waves in 2019-2022). Perhaps this is affected the delivery of megalopae late in the summer.

Over the years there have been two strong El Nino events, 1997 and 2016. Catches during these years were very low (mean=2,100, SD=1,422). There have been 15 'normal' years, i.e., no El Nino and no marine heat wave. The average catch over these years has been 8651,572 (SD=1,039,176). There have been five years characterized by marine heat waves on the continental shelf (2015, 2019-2022). Average catches during these years has been 176,469 (SD=152,531). Catch during El Nino years has clearly been significantly lower than at any other time, but we now have enough years with marine heat waves that we can test there affect. Catch during marine heat waves is higher than during strong El Nino years but catch in these years is about 5 times lower than in 'normal' years. It is not clear how a marine heat wave would affect the larval success. The marine heat wave could be affecting currents such that the delivery of larvae to the shelf waters off Oregon is lower. Ocean currents might also be altered due to the altered weather patterns that actually are the cause of the marine heat wave. Survival of larvae during the plankton pelagic stage may be lower; perhaps there is less food or more predators. In addition, very limited research suggests that warmer seawater temperatures hamper egg development, hence, if temperatures are high enough the actual output of larvae may be reduced. None of these ideas are mutually exclusive. It appears marine heat waves may be affecting larval returns, but we have no idea how.

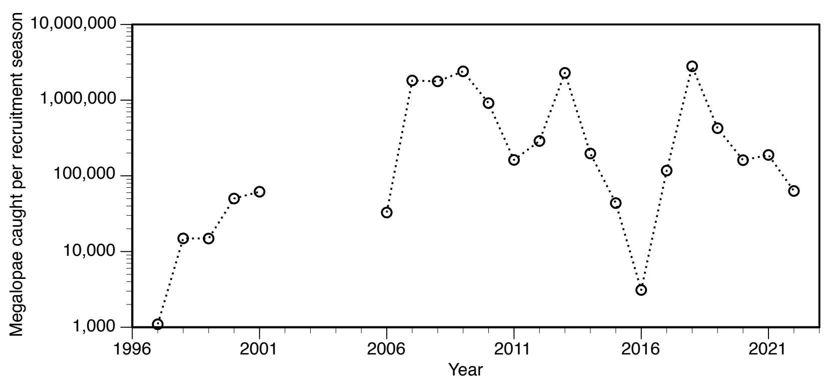

Figure 2. The annual catch of megalopae during the 22 years of study. During the first six years, catches were all < 100,000, between 2007 and 2014 catches were > 100,000. In 2015, the year of the 'warm blob', catch dropped down to 44,000 and in 2016, a year with a strong El Niño, catch was only 3,106 comparable to the catch during the last strong El Niño in 1997/1998. Catch in 2018 was a record with roughly 2.8 million megalopae caught.

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. Data from 2017 fall right at the break between these two groups and for this analysis I have placed these data with the years with lower returns of megalopae. The regression between the low catch numbers and the spring transition date continues to be significant, but the relationship between the high catch numbers and the spring transition has been degrading over the last couple of years during the marine heat waves and is now not significant. It is not clear why this might be happening. One possibility is that the day of the year of the spring transition may be shifting perhaps with climate change.

In Figure 5A I have plotted the day of the year of the spring transition vs. year. The data are noisy but there appears to be a trend to earlier spring transition dates starting at about 2010. To see this potential trend more clearly, I calculated a 5-year moving average (standard way to look at noisy time series data) and this is plotted in Figure 5B. Here it looks like starting in 2012 the spring transition is coming progressively earlier. This trend reversed this year as the spring transition was very late (DOY 162, June 11). The PDO this year was fairly strongly negative, -7.3, and historically this should have led to a very large return of megalopae, but instead we got a moderate return. The very late spring transition may be the cause for the small return. In addition, despite the negative PDO we caught no late season megalopae. And all of this was occurring during yet another marine heat wave on the shelf. How the marine heat wave plays into these data is unclear.

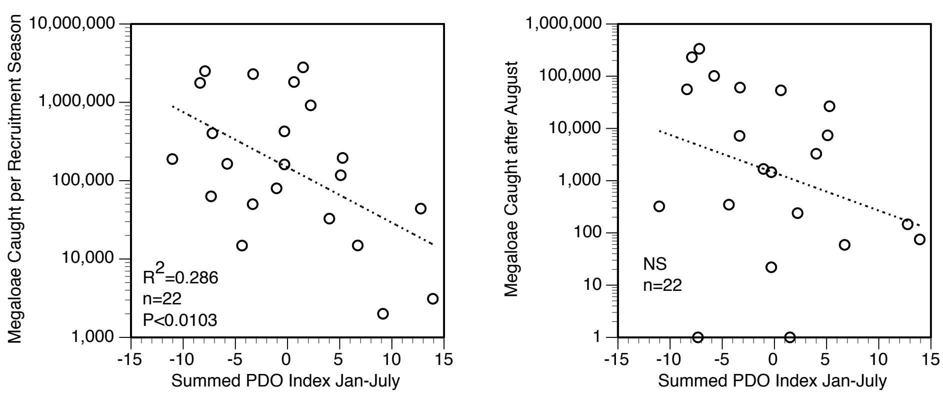

Figure 3. A) Relationship between the summed monthly PDO index from January through July and the log number of megalopae caught per season. The dashed line and statistics are the result of a regression run between the two factors. About 29% of the variability in the annual catch of megalopae is explained 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. Up until recently this relationship was significant, but in the last two years the regression has fallen apart.

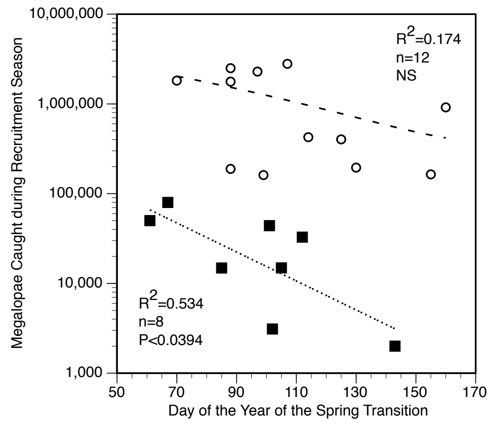

Figure 4. Day of the year of the spring transition plotted with the annual catch of megalopae. The catch data have been divided into years with low catch (<100,000 caught, filled squares) and high catch (>100,000 caught, open circles). The dotted lines and statistical results are from regressions run between the variables. The regression between the low catch numbers and the spring transition date continues to be significant, but the relationship between the high catches and the spring transition has been degrading over the last couple of years and is now not significant.

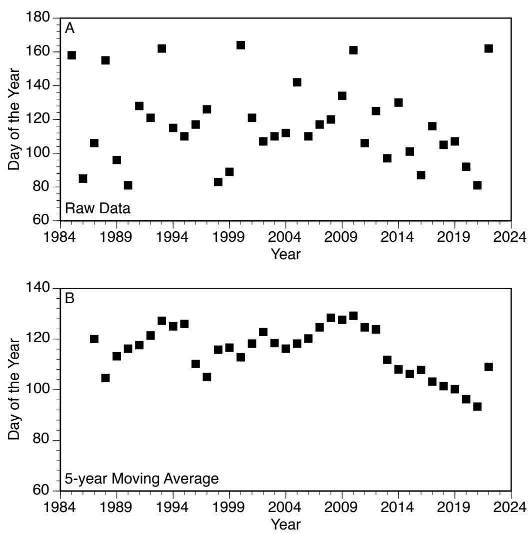

Figure 5. A) Day of the year of the spring transition vs. year. B) Five-year moving average of the day of the year of the spring transition vs. year. Notice the very late spring transition in 2023.

The relationship between the number of megalopae caught and the size of the commercial catch four years later is (currently) made up of two curves, years with low (<100,000) and high (>100,000) numbers of returning megalopae (Figure 6). I am not sure why this relationship takes the form of two curves; something different is happening post-settlement during years with high to very high returns of megalopae (i.e., when >100,000 megalopae are caught in the light trap) than occurs during years with lower returns of megalopae. Notice that there are now three data points labeled with X. These are all data from years when marine heat wave conditions were present on the shelf during the summer when the juvenile crabs are growing through their first season. Clearly the equations I have been using to predict the future commercial landings are badly under estimating landings when a marine heat wave has occurred. I think what is happening is that the juvenile crabs in the warmer water are growing faster and moving out of the very vulnerable tiny instars into larger less vulnerable instars. The net effect is that a larger percentage survives and grows into the fishery.

To investigate more carefully how well I can estimate the future commercial landings I have plotted (Figure 7) my estimated commercial landings (log metric tons) calculated from the number of megalopae caught during the recruitment season using the equations behind the regressions plotted in Figure 6, with the observed commercial landings (log metric tons). My estimates fall closely around the one-to-one line (dotted line in Fig 7). The regression between the estimated and observed landings is highly significant explaining 86% of the variability. The three filled squares, which fall way above the highly correlated data points (open circles) are the data from the three years when there were marine heat waves during the first summer the new recruits spent on the bottom. I ran a regression on these three points (and yes I know this is problematic and that is why I added ? after the data within the figure) and surprisingly the regression is significant. Unfortunately, marine heat waves are becoming a regular occurrence on the Oregon shelf. Thus far we have had heat waves in 2015, 2016 (strong El Nino), 2019, 2020, 2021, 2022, and 2023. My hunch is that ultimately we will see four curves relating the number of megalopae caught to the landings, two for years with high and low megalopae returns and no marine heat wave and two for high and low return years and heat waves. Give the regularity with which marine heat waves are currently occurring we will eventually collect enough data to test this idea.

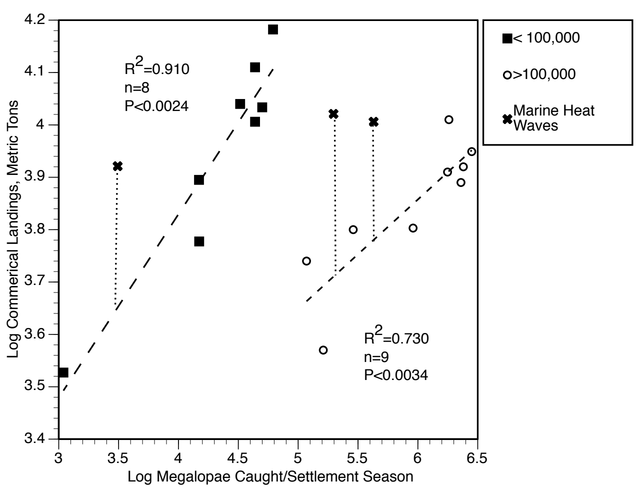

Figure 6. Log of the total number of *C. magister* megalopae caught per settlement season plotted against the log of the commercial landings lagged four years with years with catches < and > 100,000 (filled squares and open circles, respectively) plotted separately. The Xs indicate the data from years with marine heat waves in summer. Note that these data points fall between the two curves and I have not used them in the subsequent statistics nor have I used these data to calculate the future commercial landings.

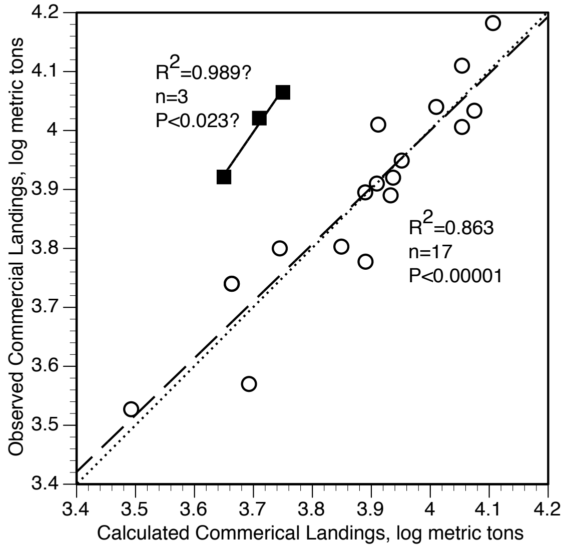

Figure 7. Estimated commercial landings calculated from the number of megalopae caught during the recruitment season plotted against the observed commercial landings. The dotted line represents a one-to-one relationship and the dashed line is the regression between the two data sets. The regression, calculated using the non-marine heat waves years (open circles) explains around 86% of the variability. The data points from the three marine heat wave years (filled squares) fall well above the regression and one-to-one lines. A regression calculated using these data is significant but statistically questionable due to the small amount of data.

Table 1. Predicted Oregon commercial catch of Dungeness crab for fishing years 2018/2019 through 2024/2025. Predictions are based on the equation from the regression curves in Fig 6.

Megalopae Recruitment Year	Log Number of Megalopae Caught	Commercial Fishing Year	Estimated Future Commercial Landings, lbs	Actual Commercial Landings, lbs
2015	4.64	2018/2019	24,730,100	≈28,393,020
2016	3.49	2019/2020	8,446,214	≈18,349,000
2017	5.07	2020/2021	8,729,129 or 35,010,300	≈12,106,086
2018	6.45	2021/2022	19,600,000	≈19,601,343
2019	5.63	2022/2023	12,400,000	≈22,391,052
2020	5.21	2023/2024	11,000,000	
2021	5.28	2024/2025	11,123,000	
2022	4.78	2025/2026	15,247,954	

Table 2. As Fig 6 and 7 indicate, marine heat waves seem to change the relationship between the number of settling megalopae and the future commercial landings. Very tentatively, it looks like marine heat waves allow a greater percentage of new recruits to grow into the fishery enlarging the commercial landings relative to my earlier predictions. In this table I present my estimated landings and the actual landings for marine heat wave years 2015, 2016, and 2019. Then, in parentheses, I present a very rough guess as to what the landings might be from the marine heat wave years 2020, 2021, and 2022. These guess estimates were made using the data in Fig 7.

Megalopae Recruitment Year	Log Number of Megalopae Caught	Commercial Fishing Year	Estimated Future Commercial Landings from Fig 6, lbs	Actual Commercial Landings and estimates from Fig 7 in ( ), lbs
2015	4.64	2018/2019	24,730,100	≈28,393,020
2016	3.49	2019/2020	8,446,214	≈18,349,000
2019	5.63	2022/2023	12,400,000	≈19,601,343
2020	5.21	2023/2024	11,000,000	(25,000,000)
2021	5.28	2024/2025	11,123,000	(22,000,000)
2022	4.78	2025/2026	15,247,954	(35,000,000)

Summary

1. The 2022 recruitment season was characterized by a negative PDO. In the past, a negative PDO has been associated with large returns of megalopae, but this was not the case this year; catch was only moderate.
2. This low catch may be due to the very late spring transition, 11 June; catch tends to vary with the spring transition, larger catches if the transition is early. Since 1984, there have been only three years with spring transition this late (1993, 2000, and 2022).
3. Starting in June, very few megalopae were caught, only 104, and none were caught after July. Usually with a negative PDO late summer catches of megalopae have been robust.
4. Marine heat waves have become a regular occurrence. They have occurred in 2015, 2016, 2019, 2020, 2021, and 2022. We now have commercial landings data and my estimates of landings from three marine heat wave years (2015, 2016, and 2019) and in each case my estimate of the future landings made using the number of megalopae that returned to the coast was low. It seems safe to say at this point that marine heat waves are affecting the recruitment success (survival) of juvenile crabs; during years when a marine heat wave is present over the shelf during the first summer of young of the year crabs, more survive and recruit into the fishery.
5. Relationships between the PDO and date of the spring transition and the catch of megalopae, relationships that had been significant, are becoming weaker. It is not clear what is causing this, but it may be due to changes in the ocean currents caused by marine heat waves.
6. We now have enough annual megalopae catch data from years with marine heat waves that we can compare catch in these years to El Nino and ‘normal’ years. Catch during marine heat waves is much higher than during strong El Nino years but almost five times lower than during ‘normal’ years.

7. Marine heat waves are clearly impacting the Dungeness crabs, but it is not obvious by what mechanism(s) this is occurring.