



CALIFORNIA WETFISH PRODUCERS ASSOCIATION

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MARKET SQUID RESEARCH PROGRAM UPDATE ~ October 2, 2014

RESEARCH RATIONALE

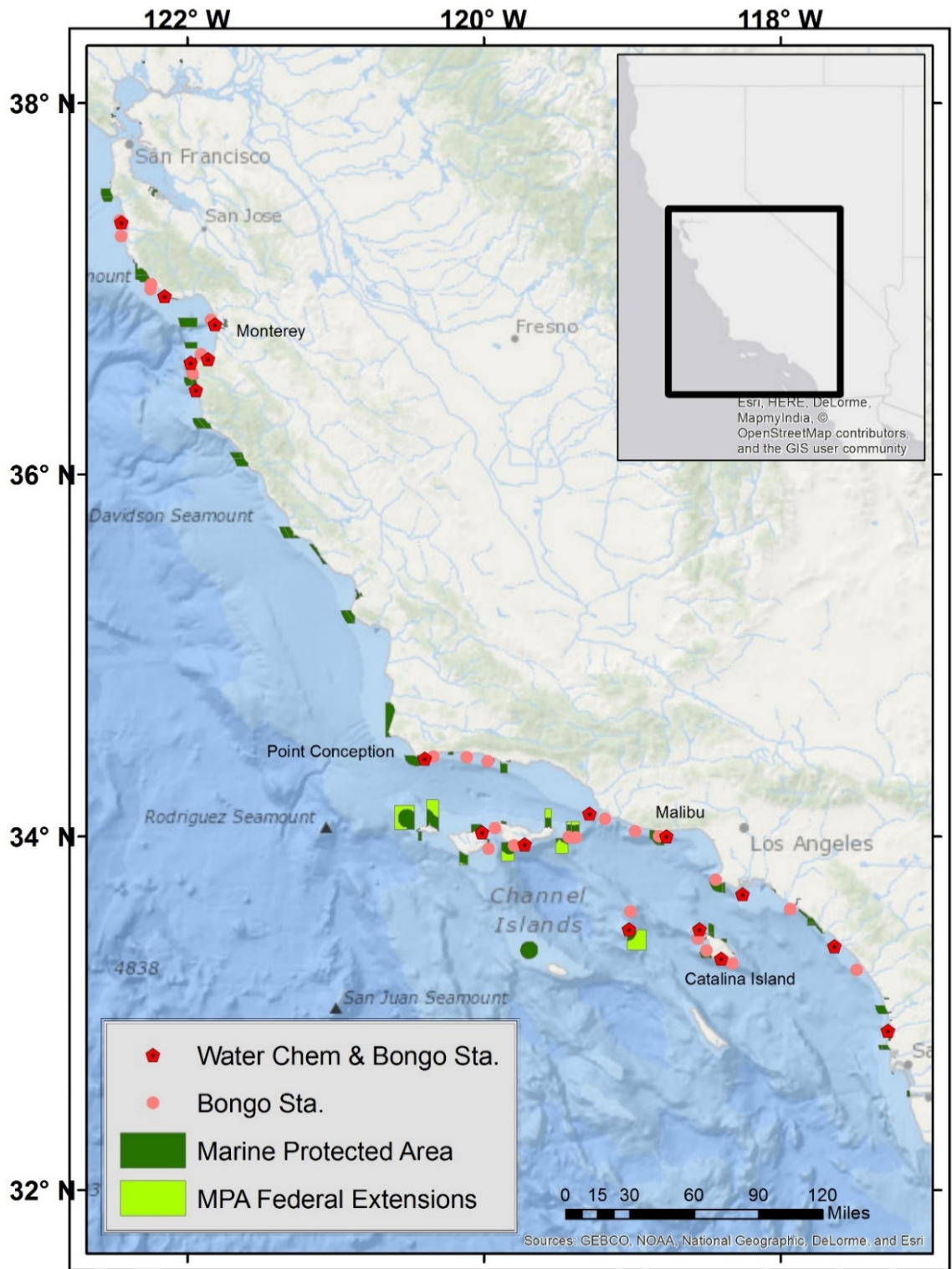
The market squid (*Doryteuthis opalescens*) fishery is the economic driver of California's historic wetfish industry, which relies on a group of coastal pelagic species (CPS) including sardines, mackerels and anchovy as well as squid. In turn, the CPS complex produces more than 80 percent of commercial seafood landings statewide, and represents close to 40 percent of statewide dockside (ex-vessel) value. (CDFW Table 15, 2010–2012).

California's wetfish industry has been actively involved in research since the beginning of the California Cooperative Fishery Investigations (CalCOFI) in the late 1940s. The nonprofit California Wetfish Producers Association (CWPA) continues the tradition as a research partner of the Department of Fish and Wildlife (CDFW) and NOAA Fisheries, Southwest Fisheries Science Center (SWFSC).

Recognizing the importance of market squid to both the ecosystem and California's fishing economy, CWPA implemented a field research program for market squid in 2005 in southern California (where on average 80 percent of landings occur), after sponsoring a workshop including state and federal fishery scientists and fishermen. The National Marine Fisheries Service provided the initial grant to develop our squid research protocol, based on research recommendations from the workshop. CWPA continued funding the program after the grant and our collaborative research continues to evolve, now focusing primarily on assessing squid paralarvae occurrence and abundance in relationship to environmental factors through seasonal bongo net tows near known squid spawning grounds.

CWPA's squid scientist Joel VanNoord now directs our research program, as we continue to collect data following the CalCOFI quarterly cruise schedule. CWPA expanded and standardized our survey area in 2011 and again in 2014, and we now sample squid paralarvae in bongo net tows at 43 sites in the Southern California Bight and Monterey Bay (Fig #1).

CWPA's squid studies encompassed the recent market squid population 'boom' during strong La Niña conditions 2010-2013. The following update summarizes preliminary findings.



(Fig. 1 Station map indicating the approximately 43 California sampling stations in the collaborative CWPA & SWFSC squid research program. The coastwide network of marine protected areas is displayed by shades of green. Pink circles indicate bongo stations to sample squid paralarvae, red symbols indicate stations where bongo tows and water chemistry samples are aquired.)

MARKET SQUID RESEARCH UPDATE – 2014

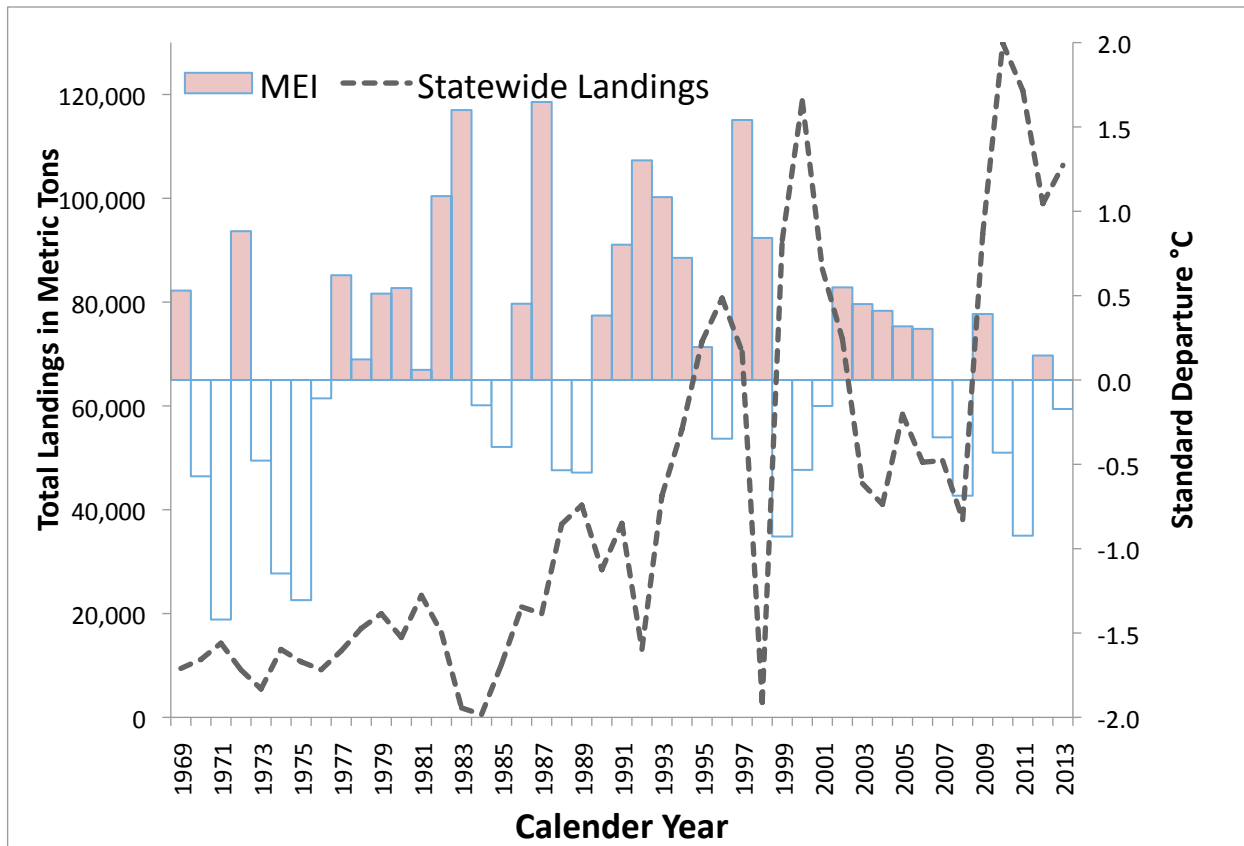
Mature market squid aggregate in massive schools over nearshore, sandy substrate in order to spawn. Females extrude egg capsules through their siphon, inserting 50 to 300 embryos in each, and anchor these egg capsules to the seafloor (Zeidberg et al. 2011). These egg mops often cover large swaths of sandy bottom. Squid die within days of spawning (Macewicz et al. 2004), while the embryos continue developing, typically over four to six weeks, depending on ocean conditions, and eventually hatch as paralarvae.



Screenshot from a video taken in Monterey Bay, August 2014, showing a sandy substrate and egg mops of various maturity. White eggs are recently laid, while opaque eggs are closer to maturation.

CWPA's research protocol continues the studies initiated by Dr. Lou Zeidberg under contract to the California Department of Fish and Wildlife. Dr. Zeidberg theorized that a Paralarvae Density Index could be developed to predict the strength of squid abundance [and the fishery] six to nine months after the field surveys. CWPA expanded and standardized the survey area in 2011, and again in 2014, when a small contract from the SWFSC enabled CWPA to extend our quarterly field surveys into the Monterey Bay area, California's historic squid fishing grounds.

The fishery for California market squid is frequently the largest and most valuable fishery in the State of California, yielding an ex-vessel value as high as \$ 74.2 million in 2010 (CDFW [Table 15](#)). As terminal spawners living less than one year, market squid populations are capable of tremendous variability in abundance. Landings fluctuate as much as 95,000 MT from one calendar year to the next (Fig. 2).



(Fig 2. Statewide California market squid landings from 1969 – 2013 shown in the dotted line by calendar year. Columns show the mean yearly multivariate ENSO index values. Red and blue values indicate warmer and colder temperatures than normal. Landings data courtesy of CDFW. MEI values from NOAA ESRL).

SQUID ABUNDANCE AND EL NIÑO

Market squid abundance is influenced strongly by oceanography, particularly El Niño Southern Oscillation (ENSO) events. During positive ENSO periods, the California Current is warmer and less productive than in normal years, yielding reduced zooplankton biomass; during La Niñas the reverse is true (Lynn et al. 1995, Chavez et al. 2002, Lavaniegos et al. 2002). Both paralarvae and adult market squid show significant increases in abundance from warm to cool ENSO states (Zeidberg et al. 2006, Koslow & Allen 2011). Following the intense 1997-98 El Niño event, squid abundance rebounded and the number of paralarvae increased from 1.5 to 78 paralarvae / 1,000 m³ off the Channel Islands in Southern California (Zeidberg & Hamner 2002) and their range expanded along the US west coast, extending as far north as Vancouver Island, Canada (Reiss et al. 2004). Market squid landings plummeted during El Niño events in 1982-83 and 1997-98, but rebounded to new highs in the strong La Niña conditions that followed, as in 1999-2001 and most recently, 2010-2013 (Fig. 2).

Higher sea temperatures pose physiological limitations on squid at multiple life history stages (Pecl & Jackson 2007). In a laboratory setting, it was found that 96% of market squid eggs were spawned at temperatures between 9 – 14 °C (48 - 57 °F, Zeidberg et al. 2011). Squid reared at lower temperatures have a greater likelihood of hatching and surviving later into life. At 12 °C, near the center of their optimal temperature range, market squid were heavier and had more egg yolk than those raised

at 16 °C (Vidal et al. 2002). Additionally, when these hatchlings were starved, the ones reared in cooler temperatures absorbed their yolk slower and survived longer (Vidal et al. 2002), indicating that lower temperatures support reduced metabolism rates and reduced food requirements at a critical phase of survival (Agnew et al. 2000, Navarro & Villanueva 2000). In more extreme temperature scenarios, squid develop malformations. A 2 °C temperature increase above current ambient temperatures resulted in metabolic suppression within the eggs of *Loligo vulgaris*, a similar squid species to the California market squid, causing premature hatching and a greater incidence of malformation (Rosa et al. 2012).

While it is evident that El Niño events cause detrimental effects on the fishery for market squid, the rapid recovery of the resource is equally remarkable. This is illustrated by landings data and the increase in occurrence of market squid in the diets of predators, such as sea lions (Lowry & Carretta 1999), and also documented by increased abundance of paralarvae in CWPA surveys. Within a four year period surrounding the 1997-98 El Niño, landings dropped from 80,000 to 3,000 mt, before rebounding to 118,000 mt (Fig. 2).

Squid show extreme life-history plasticity when confronted with either beneficial or detrimental environmental conditions (Pech & Jackson 2007); however, there is still debate whether the California market squid population declines significantly during poor conditions or moves into more suitable habitat, such as offshore banks in deeper, colder waters, where they are not fished (Reiss et al. 2004). Egg capsules and evidence of continuous interseasonal recruitment have been reported by ROV surveys in Monterey despite reduced harvest of adult market squid during the same period (Zeidberg et al. 2004), indicating that squid behavior affects the fishery during these times. In fact, reports from fishermen suggest that squid remain dispersed along the seafloor, where the water is cooler, instead of amassing into spawning aggregations near the surface; adults are not attracted by fishermen's lights during these periods (Neil Guglielmo, pers. comm).

ECOSYSTEM ROLE

Market Squid play a key role in marine food webs by transferring energy from lower to higher trophic levels (Gasalla et al. 2010, Coll et al. 2013). Market squid are also important predators of zooplankton themselves, particularly euphausiids (Karpov & Cailliet 1979, Van Noord unpubl.), as well as prey for many fish, bird, and mammal species (Lowry et al. 1991, Ainley et al. 1996, Preti et al. 2004). Squid directly influence prey populations. The large and voracious jumbo squid (*Dosidicus gigas*) was estimated to consume 60,000 mt of sardine during a nine-month residency in the Gulf of Mexico, possibly contributing to unusually high sardine mortality (Ehrhardt 1991). Jumbo squid similarly impacted hake off central Chile (Alarcón-muñoz et al. 2008). Other neritic squids, such as the northern shortfin squid (*Illex illecebrosus*, > 20 cm in length) can consume up to 6.7% of their body weight daily in prey (O'Dor et al. 1980). The pelagic, neon flying squid (*Ommastrephes bartramii*) was estimated to remove 5 – 12% of the total daily biomass of one of its preferred prey items—a myctophid fish (Watanabe et al. 2004). The effect of market squid predation on zooplankton biomass or species composition in the California Current has not been directly assessed, but considering the energetic demands of this animal and its population size, the effect is surely not negligible.

Given the dynamic variability in forage fish populations within the California Current, notably sardine, anchovy, hake and market squid (Chavez et al. 2003, Dorval et al. 2013, Lindegren et al. 2013), it follows that predators of market squid and these fishes would require a flexible diet in response. And, indeed, many top predators in the California Current, and elsewhere, are opportunistic feeders that

consume prey in proportion to the species available in the ecosystem at the time. Furthermore, the diet composition of many top predators has been linked to changes in prey abundance, hypothesized to be driven by shifts in warm to cool oceanographic regimes (Miller & Sydeman 2004, Glaser 2010, Olson et al. 2014). In fact, the diet of seabird species is often used as a proxy for the abundance of prey species; such is the case in the Gulf of California where sardine consumption by the elegant tern was strongly correlated to catch per unit effort for sardine (Velarde et al. 2004). Additionally, the diet of thresher sharks in the California Current shifted from anchovy and squid during cool periods, to sardine and crab during warm periods (Preti et al. 2004). While many top predators are opportunistic feeders, prey nutrition varies greatly between fish, cephalopods, and krill (Sikorski et al. 1990). These nutritional differences affect predator health, recruitment, and breeding success (Baird 1990, Merrick et al. 1997). For example, female California sea lion diets that are dominated by squid and juvenile rockfish are correlated with reduced pup size and increased pup mortality (Melin et al. 2012).

MARKET SQUID MANAGEMENT

Management agencies are mandated by both state and federal law to monitor fish populations and establish maximum harvest limits for fisheries to ensure the sustainability of both the resource and the fishery. This process generally involves establishing biomass estimates of the population and determining optimum yield for the fishery, (maximum sustainable yield [MSY], reduced by ecosystem considerations), to retain a sufficient biomass of the population in the ocean to reproduce.

However, these general rules for setting fishery quotas are difficult to apply to squid. Market squid live less than one year, die after spawning, and have dynamic swings in abundance with highly variable growth rates dependent on sea temperature, food availability, and natural oceanic productivity. Therefore, establishing a biomass estimate poses considerable challenges (see Dorval et al. 2013).

To address management of this species, market squid are both monitored under the federal Coastal Pelagic Species Fishery Management Plan (CPS FMP) and actively managed by the California Department of Fish and Wildlife under the Market Squid Fishery Management Plan (MSFMP) and Marine Life Management Act.

In both the CPS FMP and MSFMP, egg escapement, with a target to achieve 30%, serves as MSY proxy, in lieu of numerical biomass estimates. Market squid are also managed through a series of time and area closures. Weekend fishing closures, which prohibit the harvest of squid from noon Friday until noon Sunday, allow periods of uninterrupted spawning. Coincidentally, weekend closures approximate 30 percent of the week. In addition, a network of no-fishing marine protected areas (MPAs), which has closed an estimated 25 percent or more of traditional squid spawning/fishing grounds in central and southern California, also serves to protect key spawning locations and egg escapement. Additional management restrictions include limited entry for fishing vessels, and a maximum annual harvest limit of 107,047 metric tons. If the max cap is attained, the directed fishery is closed. State and federal biologists are now assessing the success of these egg escapement measurements by sampling the reproductive status of squid landed by the industry.

CWPA COLLABORATIVE RESEARCH

With such a dynamic and valuable resource, CWPA saw the need to better understand and document squid population fluctuations in order to provide information to monitor and help verify sustainable fishery management. With our research efforts we are interested in accomplishing the following objectives:

Paralarvae abundance study

1. Establish a long term index of paralarvae abundance in southern California and the greater Monterey Bay region.

This will allow us to monitor the population dynamics of squid and how those patterns relate to oceanography, particularly ENSO cycles. With this fine-scale sampling, we will also:

2. Investigate site-fidelity.

Knowing whether squid preferentially return to certain areas, and what biotic and abiotic parameters those regions share, can help identify critical habitats for squid. This will also help fishery managers understand the efficacy of marine protected areas in promoting squid paralarvae abundance.

3. Establish an index between paralarvae and landings data.

This will allow us to estimate relative landings and timing of the fishery by establishing an index between paralarvae abundance and adult landings using a defined time lag.

Food habits

ENSO cycles demonstratively influence the abundance of market squid, but questions still exist as to exactly how and why these oceanographic changes affect squid. Since squid have high energetic demands, and El Niño's are inversely related to productivity and zooplankton biomass, reduced feeding success and changes in diet composition could be related to population declines. Therefore, we aim to:

4. Determine the diet of paralarvae, juvenile, and adult squid, assess how diet changes over space and time, and how diet relates to abundance.

Efforts can also be made to estimate the daily ration of krill consumed by market squid, in order to gauge the effect these predators have on key components of the zooplankton community.

Collaboration

Through a collaboration with federal scientists at NOAA's SWFSC, we have been able to expand our survey efforts into northern California to better assess the dynamics of the squid fishery, including the use of drop cameras to video the evolution of egg beds in association with our bongo net tows. With these collaborative efforts, we hope to assist state and federal biologists with improving current stock assessment models (see Dorval et al. 2013). CWPA also supports new efforts to update current

methodologies to monitor egg escapement, using mantle characteristics, for example. This, along with current ageing techniques, will help monitor the ecosystem effects of the fishery. Directly, CWPA and NOAA SWFSC aim to:

5. Assess the growth and survivorship of market squid off California from paralarval to juvenile life stages

This will involve developing an ageing program for juvenile and paralarvae squid, allowing us to evaluate stock structures of squid at different life stages to assess survival from paralarvae to juvenile to adults, and how that ratio may change during ENSO periods. This will help expand understanding of how the environment influences resource abundance relative to the fishery.

6. Assess the natal origin of squid to understand population connectivity between northern and southern California fisheries.

Using stable isotopes and unique trace elemental signatures found in the water column at different locations and in squid statolith cores, we hope to determine the birth place of adult squid landed at different locations throughout California.

This information will help fishery managers ensure that market squid are harvested in a responsible and sustainable manner for the health of the ocean ecosystem and the benefit of coastal communities. CWPA aims to help in providing a continuous baseline estimate of spawning production, assist in the improvement of existing stock assessment models, verify the efficacy of current management practices, and research basic ecological aspects of this important marine species.

CWPA'S UNIQUE AND IMPORTANT CONTRIBUTION

CWPA's squid research program is the only on-going research survey targeting squid paralarvae in nearshore spawning habitats. This growing database provides a continuous reference point for paralarvae abundance within the Southern California Bight and now, Monterey Bay, providing a prediction of adult squid abundance available to the fishery six-to-nine months in advance. This prediction can be helpful for management purposes, including in-season accounting.

In light of the dynamic population fluctuations of the market squid resource (Fig. 3), we are striving to understand how ENSO cycles affect squid paralarvae, an early life history stage, which can help managers anticipate the productivity of the coming fishing season. Additionally, our paralarvae data can assist in stock assessment models by providing a relative measurement of spawning, and work in conjunction with other programs, such as CalCOFI, to estimate mortality rates from paralarvae to juvenile and adult life stages.

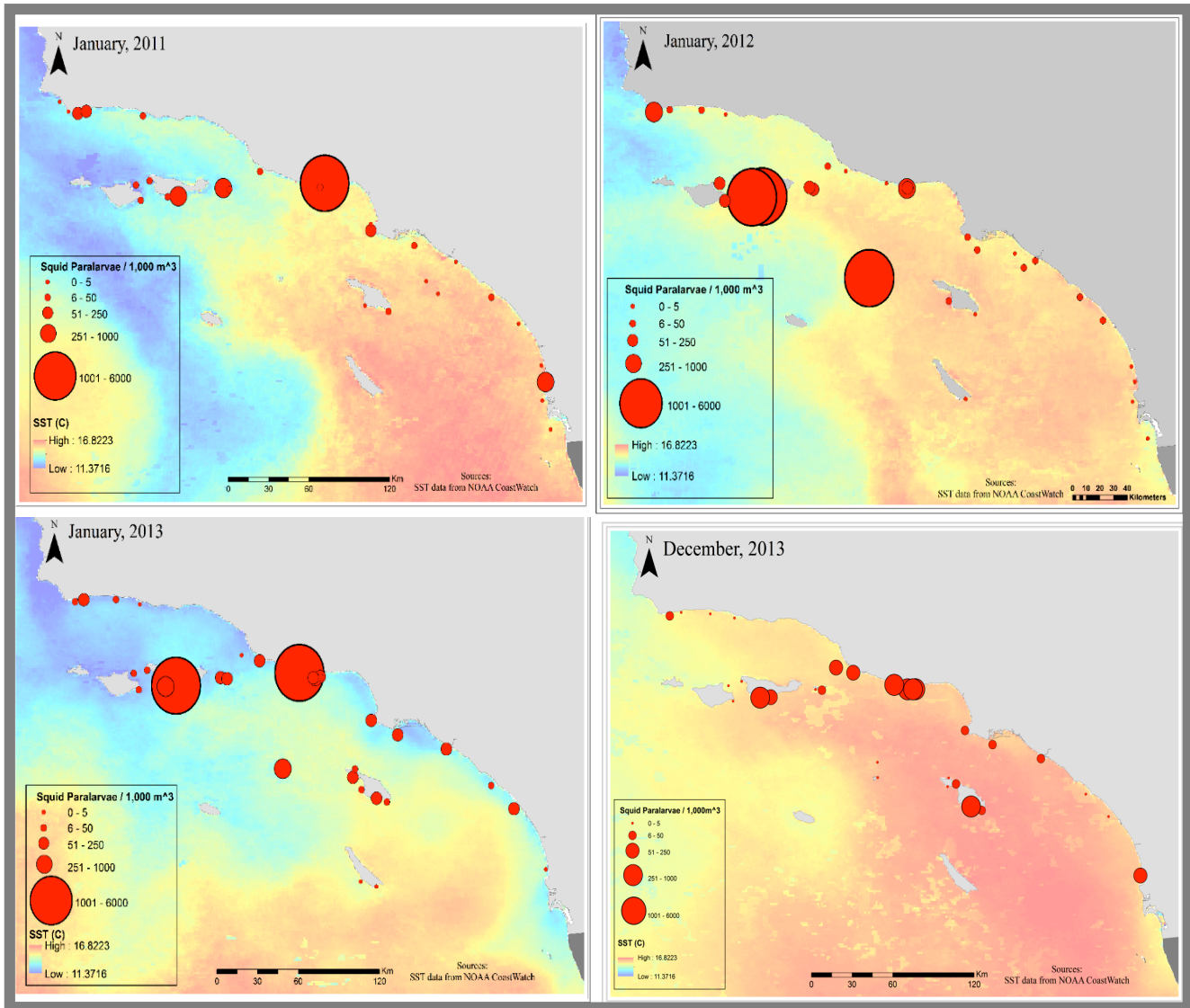


Fig 3. This figure exemplifies CWPA's market squid field research program, which has documented dynamic variability in paralarvae concentrations between and among areas and seasons.

PARALARVAE SAMPLING PROTOCOL



We sample squid paralarvae using an obliquely towed bongo net, targeting the same nearshore, shallow-water (~30-100 m), spawning locations yearly and seasonally. Since squid exhibit diel movements, being found higher in the water column at night (Zeidberg & Hamner 2002), nets are towed at 13 meters (7 fathoms or 42 feet) depth at nighttime and 27 meters (15 fathoms, 90 feet) during daylight. Four annual surveys occur in the months of January-February, July, and November-December, in part timed to coincide with seasonal CalCOFI cruises that are conducted primarily offshore (see: <http://calcofi.org/> for program overview, Fig. 4). Attached to the net frame is a flowmeter, which allows us to standardize our catch to individuals / 1,000 m³.

Deploying a bongo net off the F/V Seajay



Rinsing the net aboard the F/V Donna Kathleen



Deploying the “Sea Star” video system, developed by the Monterey Bay Aquarium Research Institute, to monitor squid egg beds.

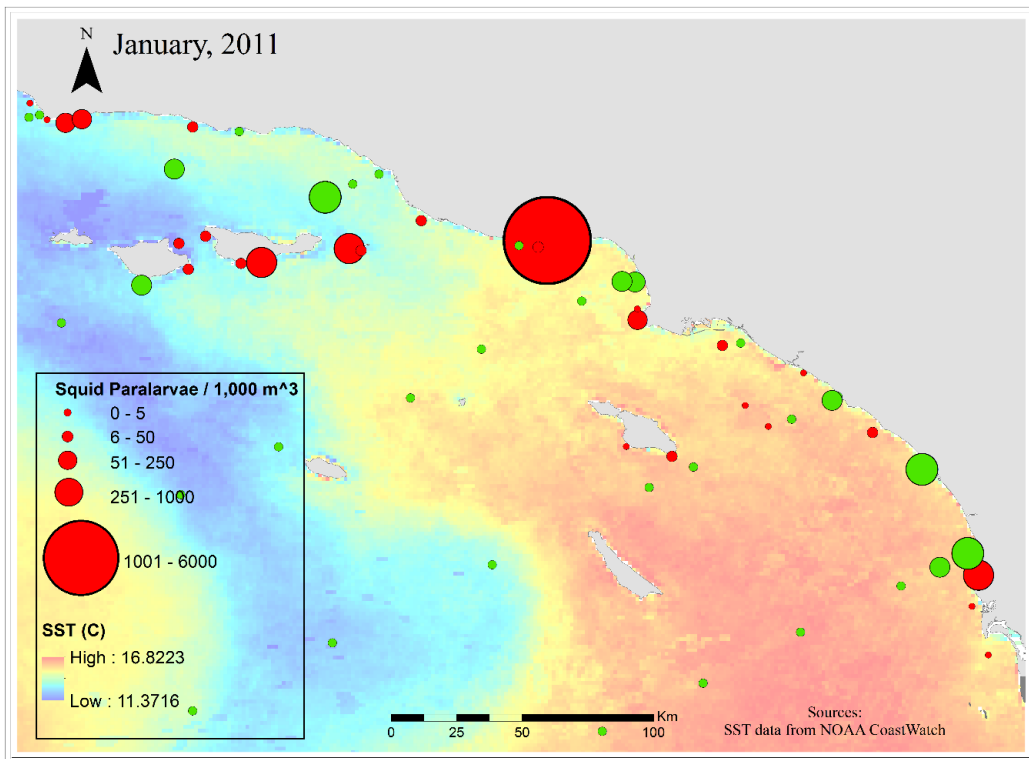


Fig 4. Sea Surface Temperature (SST) and paralarvae abundance data from January, 2011 showing efforts from the CWPA in red, and CalCOFI in green. The green stations highlight the predominately east to west grid pattern of the CalCOFI research program, while CWPA efforts highlight a nearshore emphasis, particularly around the Channel Islands.

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