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Seasonal oceanography from physics to micronekton in the south-west Pacific

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A B S T R A C T

Tuna catches represent a major economic and food source in the Pacific Ocean, yet are highly variable. This variability in tuna catches remains poorly explained. The relationships between the distributions of tuna and their forage (micronekton) have been mostly derived from model estimates. Observations of micronekton and other mid-trophic level organisms, and their link to regional oceanography, however are scarce and constitute an important gap in our knowledge and understanding of the dynamics of pelagic ecosystems. To fill this gap, we conducted two multidisciplinary cruises (Nectalis1 and Nectalis2) in the New Caledonian Exclusive Economic Zone (EEZ) at the southeastern edge the Coral Sea, in 2011 to characterize the oceanography of the region during the cool (August) and the hot (December) seasons. The physical and biological environments were described by hydrology, nutrients and phytoplankton size structure and biomass. Zooplankton biomass was estimated from net sampling and acoustics and micronecton was estimated from net sampling, the SEAPODYM ecosystem model, a dedicated echosounder and non-dedicated acoustics. Results demonstrated that New Caledonia is located in an oligotrophic area characterized by low nutrient and low primary production which is dominated by a high percentage of picoplankton cyanobacteria *Prochlorococcus* (> 90%). The area exhibits a large-scale north–south temperature and salinity gradient. The northern area is influenced by the equatorial Warm Pool and the South Pacific Convergence Zone and is characterized by higher temperature, lower salinity, lower primary production and micronekton biomass. The southern area is influenced by the Tasman Sea and is characterized by cooler temperature, higher salinity, higher primary production and micronekton biomass. The dynamic oceanography and the complex topography create a myriad of mesoscale features including eddies, inducing patchy structures in the ecosystem. During the cool season, a tight coupling existed between the ocean dynamics and primary production, while there was a stronger decoupling during the hot season. There was little difference in the composition of mid-trophic level organisms (zooplankton and micronekton) between the two seasons. This may be due to different turnover times and delays in the transmission of primary production to upper trophic levels. Examination of various sampling gears for zooplankton and micronekton showed that net biomass estimates and

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acoustic-derived estimates compared reasonably well. Estimates of micronekton from net observations and the SEAPODYM model were in the same range. The non-dedicated acoustics adequately reproduced trends observed in zooplankton from nets, but the acoustics could not differentiate between zooplankton and micronekton and absolute biomasses could not be calculated. Understanding the impact of mesoscale features on higher trophic levels will require further investigation and patchiness induced by eddies raises the question of how to best sample highly dynamic areas via sea experiments.

1. Introduction

In the South Pacific Ocean fishing of apex predators, such as tuna and billfishes, represents a major economic and food resource (Bell et al., 2013). Considerable variability in tuna catch rates is observed in fisheries (Rouyer et al., 2008). Although much of this variability remains unexplained, tuna abundance in space and time has been correlated with factors including oceanographic conditions, physiological constraints (e.g. temperature, depth, oxygen requirements), forage availability, and reproductive behavior (Farley et al., 2013; Senina et al., 2008; Young et al., 2011).

Tuna forage predominantly comprises micronekton (Young et al., 2010; 2015). Micronekton are defined as organisms in the 2–20 cm size range and are predominantly distributed in the upper 1000 m of the water column. Micronekton play a key role as intermediaries between plankton production, their prey, and top predators. Since micronekton biomass is dependent on the availability of plankton prey, it is expected that plankton production, its oceanographic drivers, and micronekton biomass would be tightly coupled, and therefore act in concert in determining top predator distributions.

The New Caledonian Exclusive Economic Zone (EEZ), a region of more than 1.4×10^6 km², is located in the Coral Sea, at the southeastern edge of the South Pacific (Fig. 1). The dominant feature of circulation across 0–150 m is the westward-flowing South Equatorial Current (SEC) from $\sim$25°S to the equator. The SEC flow bifurcates at the Australian continental margin (Ridgway and Dunn, 2003) at $\sim$15°S, with one branch connecting with the southward flowing East Australian Current (EAC) (Qu and Lindstrom, 2002) and the other forming the Gulf of Papua Current which flows northward along the coast of Queensland. Within the Coral Sea, the SEC comprises narrow filaments and jets created by the complex island, reef, seamounts and ridge topography (Gourdeau et al., 2008) namely the North Vanuatu Jet at around 13–15°S, and the North Caledonian Jet at around 17–18°S (Couvelard et al., 2008; Marchesiello et al., 2010). To the south of New Caledonia, the surface flow returns from the EAC back into the central south Pacific (Fig. 1) as the South Tropical Counter Current (STCC) (Marchesiello et al., 2010). In this region, the structures of the ocean currents are prone to shear instabilities and high eddy kinetic energy is observed (Qiu et al., 2009). Excluding the very coastal areas, the New Caledonian EEZ is regarded as oligotrophic (Dandonneau and Gohin, 1984) with a mean nitracline depth of $\sim$110 m (Fig. 1). South of 22°S, the region experiences higher productivity (Ceccarelli et al., 2013; Dandonneau and Gohin, 1984).

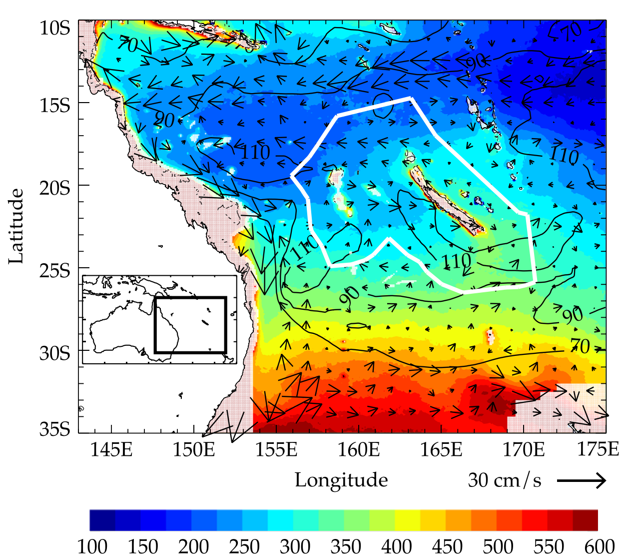

Fig. 1. Mean 1998–2007 primary production estimated from satellite (VGPM) in mgC m^{-2} d^{-1} (shading). Regions of ocean depth shallower than 200 m have been blocked out. Mean depth of the 1 μM nitrate isopleth (proxy for the nitracline depth) was extracted from CARS climatology (http://www.marine.csiro.au/~dunn/cars2009/) (Ridgway et al., 2002) in meters (contour lines) and mean 0–150 m total geostrophic currents sourced from Kessler and Cravatte (2013) (vectors). The New Caledonia Exclusive Economic Zone is delineated by the white line.

Within this oceanographic context, the longline fishery for tuna represents approximately 30% of the total fisheries harvest in New Caledonia (Gillett, 2009). Catches are dominated by albacore tuna (*Thunnus alalunga*) and exhibit two seasonal peaks in July–August and December, and the highest catch rates occur in the northwestern part of the EEZ (Briand et al., 2011). The influence of temperature, primary production and micronekton density on tuna catch rates has been demonstrated in New Caledonia (Briand et al., 2011), in American Samoa (Domokos, 2009) and at the ocean basin scale in the Pacific Ocean (Lehodey et al., 1998).

Large-scale observations of temperature, surface currents and surface primary production derived from satellite data have allowed validation of the existing oceanographic models, giving confidence in the use of modeled oceanographic parameters for such analyses. However there are few observations of biological parameters, including micronekton, to validate the model biological outputs.

At the scale of the South Pacific, nutrient and in situ phytoplankton data are sparse, as are data on zooplankton (Carassou et al., 2010; Le Borgne et al., 2011; McKinnon, 2005; Young et al., 2011). Knowledge of the micronektonic communities and their distributions is somewhat more comprehensive, but is based primarily on top predator diet studies (Allain et al., 2012; Olson et al., 2014; Young et al., 2011, 2010). Few data are available from in situ sampling with nets in the South Pacific (Flynn and Paxton, 2012; McPherson, 1991) and in general, none of the available micronekton data are coupled with information on oceanographic conditions. These constitute important gaps in our knowledge and understanding of the dynamics of the pelagic ecosystem.

Prior to this study, in situ data on micronekton in the New Caledonian region were derived from a handful of studies conducted in the eastern part of the EEZ (Grandperrin, 1975, 1969; Legand et al., 1970; Roger, 1986, 1974). Overall, data from the New Caledonia region are limited in both space and time, prohibiting a comprehensive description of the pelagic ecosystem, including the main seasonal patterns of zooplankton and micronekton and their relationships with the oceanography.

In 2011, we conducted two dedicated multi-disciplinary bio-oceanographic cruises (Nectalis1 and Nectalis2) in an effort to fill