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The oceanography of the Subtropical Frontal Zone in the central North Pacific and its relevancy to the Hawaii-based swordfish fishery[1]

Michael P. Seki, Jeffrey J. Polovina,
Donald R. Kobayashi, and Bruce C. Mundy

Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822 U.S.A.

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The oceanography of the Subtropical Frontal Zone in the Central North Pacific and its relevance to the Hawaii-based swordfish fishery.

by

Michael P. Seki, Jeffrey J. Polovina, Donald R. Kobayashi, and Bruce C. Mundy
National Marine Fisheries Service, NOAA
Southwest Fisheries Science Center Honolulu Laboratory
2570 Dole Street
Honolulu, HI 96822-2396

During the peak winter-spring fishing season, the Hawaii-based swordfish fishery generally operates in a region north of the Hawaiian Archipelago nominally referred to as the Subtropical Frontal Zone (STFZ) (Fig. 1). The STFZ stretches laterally across the central North Pacific Ocean over several degrees of latitude and dynamically represents an area where at the surface cooler, lower salinity water formed in part of subarctic origin converges with warmer, saltier subtropical water found to the south. Multiple, large-scale individual semi-permanent fronts, the most prominent climatologically located at 32°-34°N and at 28°-30°N latitudes, are typically associated with the frontal zone meridional boundaries. Because of the incomplete balance that exists between the temperature and salinity gradients, fronts in the STFZ also exhibit moderate to significant density gradients; the strongest occurring in the subtropics, diminishing northward with poleward cooling of surface waters. On synoptic time scales, pervasive mesoscale (order of 1-100 km) processes in the form of meandering fronts and frontal eddies are often embedded in the frontal zone, locally deforming near-surface gradients. These fronts and deformations give rise to a highly dynamic baroclinic flow field and fluctuations in sea level height whose surface expressions are readily measured by satellite altimeters.

Because of the highly dynamic nature of the STFZ fishing grounds on varying temporal and spatial scales, a multi-platform approach (i.e., satellite remote sensing and in situ shipboard surveys) to environmental assessment, was undertaken. Satellite mounted sensors provide near real-time synoptic data coverage on the large scale. We particularly found TOPEX/POSEIDON altimetry, which measures sea surface height (SSH) along tracklines with complete global coverage every 10-days, a valuable tool in assessing the condition of the swordfish fishing grounds north of Hawaii. By spatially interpolating SSH between tracklines and computing the gradient of the SSH surface, geostrophic currents and fronts are computed. In situ surveys, which principally involve a series of conductivity-temperature-depth (CTD) casts and discrete depth water sampling stationed along meridional transects, describe processes that occur on the local and meso-scale and provide the information necessary for ground truthing and subsurface interpretation of the satellite tools.

A TOPEX SSH map (Fig. 2) illustrates the highly energetic STFZ as a broad region of large sea level height gradients and high geostrophic current velocities meandering between 26° and 32°N latitudes. A pervasive field of mesoscale activity in various stages of formation and decay is seen to characterize the STFZ with cyclonic eddies and meanders prevalent to the north of the strongest frontal current streamlines and anticyclonic features to the south. In situ hydrographic sections corresponding to the satellite altimeter cycle confirm and further elucidate the salient properties that define the fishing grounds. In vertical sections of temperature (t) and salinity (s) (Fig. 3), the boundaries of the STFZ can be seen positioned at about 32°N latitude to the north ($t < 18°C$, $s < 34.8$ PSU) and around 28°N latitude to the south ($s > 35.0$, $t > 18.5°C$). Thermohaline surface gradients, which form the high stability layer at depth, are steepest at the boundary fronts; particularly to the south where at 28°N latitude, $\Delta T \approx 3°C \cdot 50\ km^{-1}$, $\Delta S \approx 0.7\ PSU \cdot 50\ km^{-1}$, and $\Delta \sigma_t \approx 0.6 \cdot 50\ km^{-1}$ and thermo- and halo-cline depths shoal northward in a stepwise fashion with increments in alignment with front locations. As cooler, less saline and higher density water from the north sinks below the warmer, higher saline water to the south at the fronts, localized secondary divergence and convergence also develops and appear in the vertical sections as uplifted and depressed isoclines marking regions of upwelling and downwelling, respectively.

Biologically, the vertical distribution of chlorophyll standing stock ($mg\ Chl \cdot m^{-3}$) matches up well with its corresponding density (σ_t) structure, particularly with regards to pycnocline depth and presence/absence of the subtropical high-stability layer (Fig. 4). In waters to the south and within the STFZ of this particular section, total chlorophyll (integrated vertically from 10-200 m) ($mg\ Chl \cdot m^{-2}$) averaged 27.7 $mg \cdot m^{-2}$ (sd = 2.9) and 29.0 $mg \cdot m^{-2}$ (sd = 6.3), respectively; high values were typically measured at stations associated with uplifted isopycnals (Fig. 4). Total chlorophyll exhibits stepwise patterns similar to its corresponding physical parameters with increasing concentrations moving northward along the track. Enhanced levels of total chlorophyll in the subtropical waters are generally ascribed to increases in the concentration and thickness of the subsurface Chl maximum (Chl-max) layer prompted by the shoaling of the nutricline with the thermohaline structure into the euphotic zone. The central subtropical Pacific Ocean is typified by a deep Chl-max layer of concentration 0.2-0.4 $mg \bullet m^{-3}$, generally located at about 90 m depth; parameters consistent with that observed at stations sampled away from upwelling activity. Peak concentrations in the Chl-max observed here exceeded 1.0 $mg \bullet m^{-3}$. To the north of the STFZ in Transition Zone waters, a substantial increase in chlorophyll standing stock is measured; $\overline{Chl} = 36.1\ mg \cdot m^{-2}$ (sd = 6.0). The abrupt increase in total chlorophyll is believed to be a response to the absence of the high-stability layer in the Transition Zone, facilitating the flux of nutrients into surface waters; hydrostatic stabilities are reportedly lower in the Transition Zone than anywhere else in the open North Pacific. Vertical distribution patterns of nutrients (nitrate+nitrite, phosphate and silicate) are also consistent with that expected from the section's density structure. Depths of the chlorophyll maximum typically coincided with the nutricline depth (defined as the 1.0 μM N-isopleth).

Relationships between the physical environment and higher trophic levels have been considerably more difficult to ascertain, primarily due to the difficulty in acquiring the necessary biological information for such an assessment. An ongoing swordfish diet study suggests opportunistic feeding on available surface dwelling prey but identifies a predilection for squid particularly among fish sampled during the winter months of the fishing season. Limited information from research surveys have suggested substantially higher squid abundance (*Ommastrephes bartramii*) occurring at regions adjacent to the cold side of the southern front of the STFZ. Correspondingly, swordfish catch rates are also highest in the vicinity along the same front during this time period. During spring however, swordfish are believed to begin a migration southward to spawn. A southerly shift in the spatial distribution of the fishing fleet effort and locations of high catch sets away from the STFZ to waters just north of Hawaii support this supposition. The proportion of squid composing the swordfish diet decreases with shift in season as well (Fig. 5).

Our efforts to assess the oceanography and habitat associated with swordfish and the swordfish fishing grounds are ultimately intended to help interpret fishery performance. To this goal, TOPEX SSH may provide information on environmental factors which impact seasonal and interannual variation in swordfish longline catch-per-unit-of-effort (CPUE). We have observed that the area targeted by the Hawaii-based longline fishery for swordfish exhibits seasonal variation in SSH in excess of 10 cm between vertically mixed winter conditions and stratified summer conditions (Fig. 6). Further seasonal and interannual variation in SSH shows a high (inverse) coherence with CPUE; a drop (rise) in SSH corresponds to a rise (fall) in swordfish CPUE. Work to understand and use variation in SSH in the fishing ground to explain environmentally induced variability in fishery CPUE is ongoing.

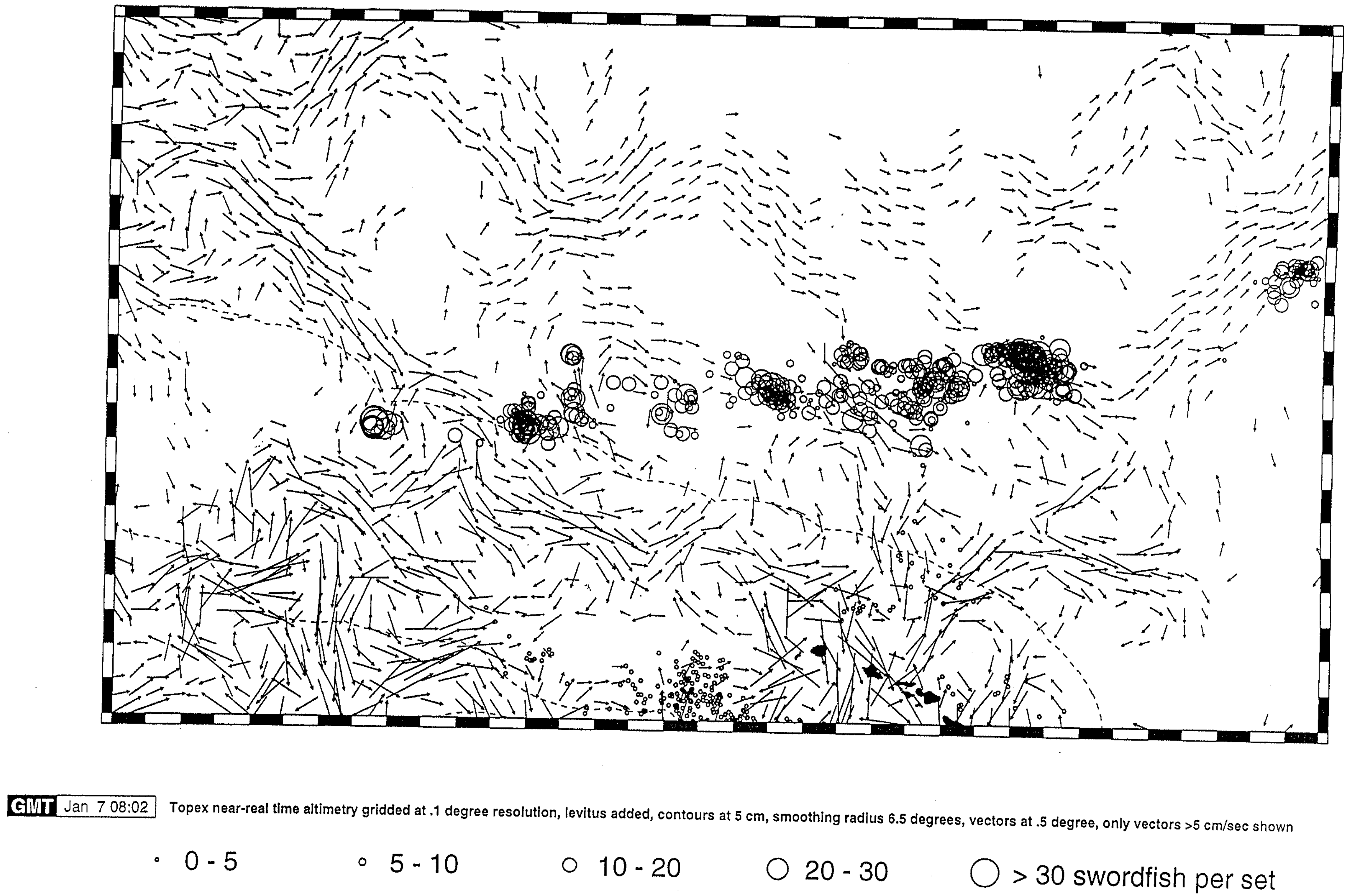

Figure 1. Geostrophic currents estimated from TOPEX/Poseidon and swordfish CPUE from the Hawaii longline fishery, March 1997.

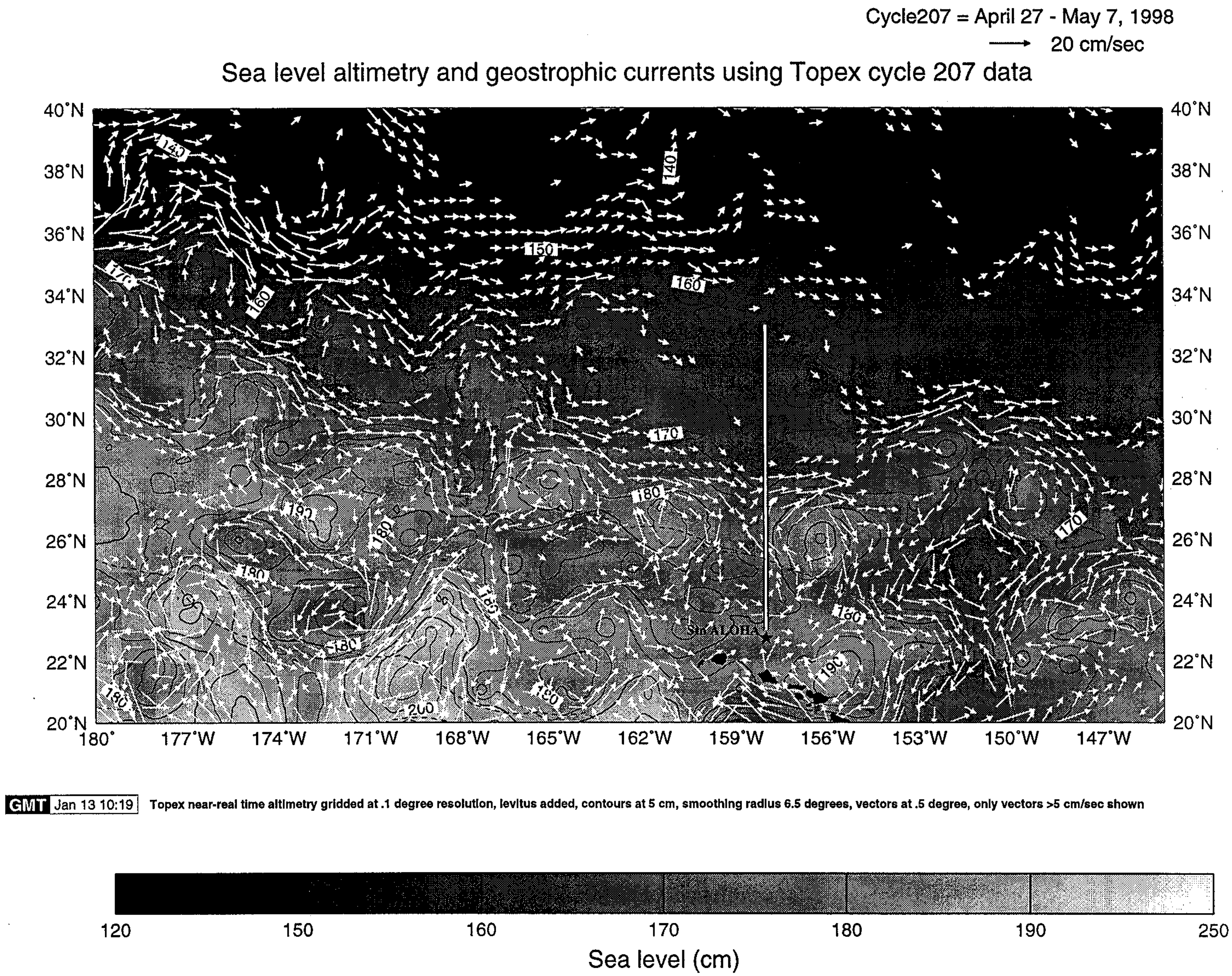

Figure 2. Map of sea level height (with the Levitus long term mean dynamic height at 1000 m added) from the altimeter aboard TOPEX/POSEIDON for cycle 207, 27 April - 7 May 1998. Bold vertical line illustrates the location of a shipboard hydrographic transect conducted along 158°W longitude concurrent to the cycle. Shading and 5 cm contours represent altimetry gridded at 0.1° resolution and a smoothing radius of 6.5°. Corresponding geostrophic current velocities (vectors) are presented for 0.5° spatial resolution; only velocities > 5.0 cm·sec^{-1} are shown.

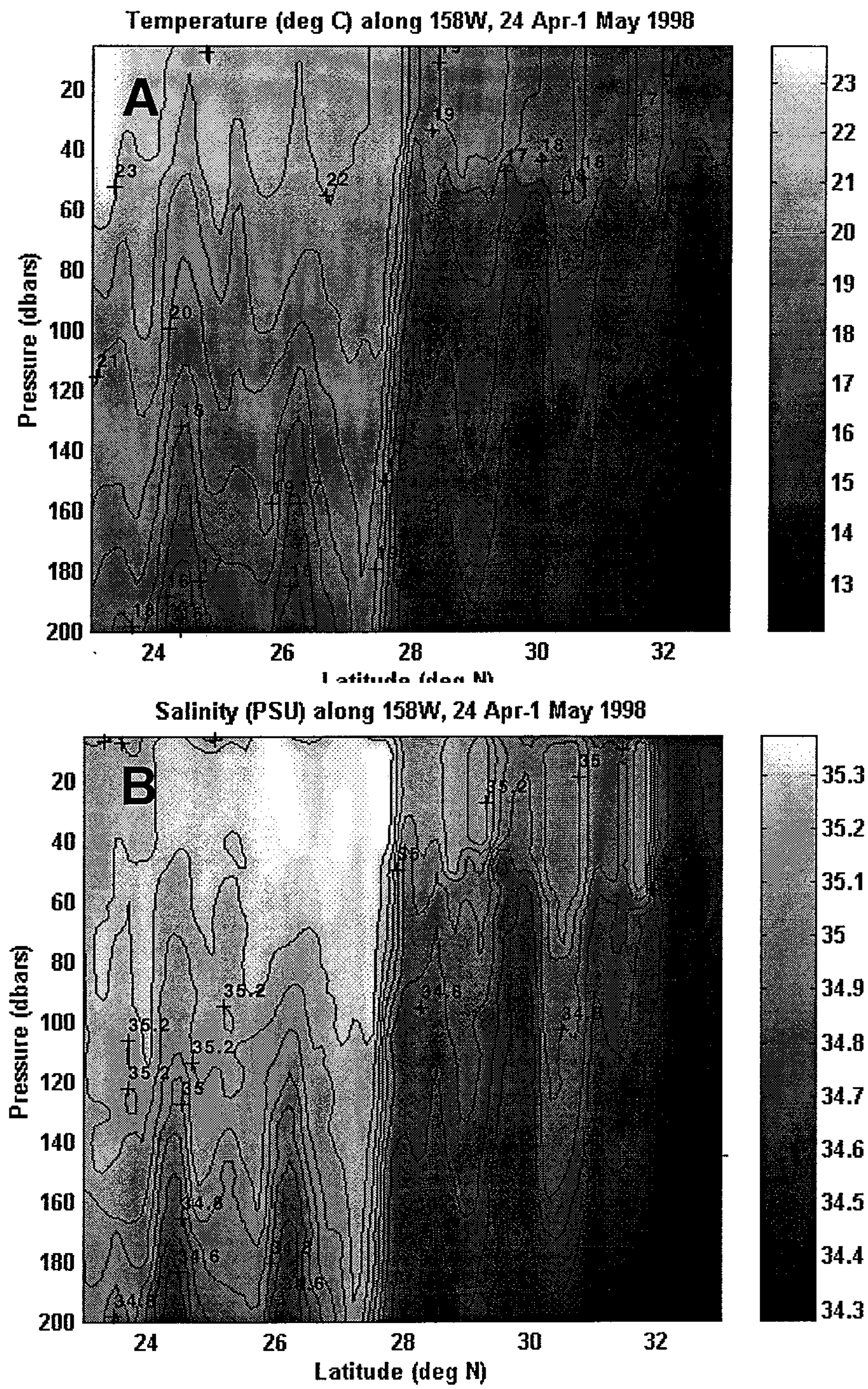

Figure 3. Meridional section of (a) temperature and (b) salinity over the surface-200 m depths along 158°W longitude, 24 April - 1 May 1998.

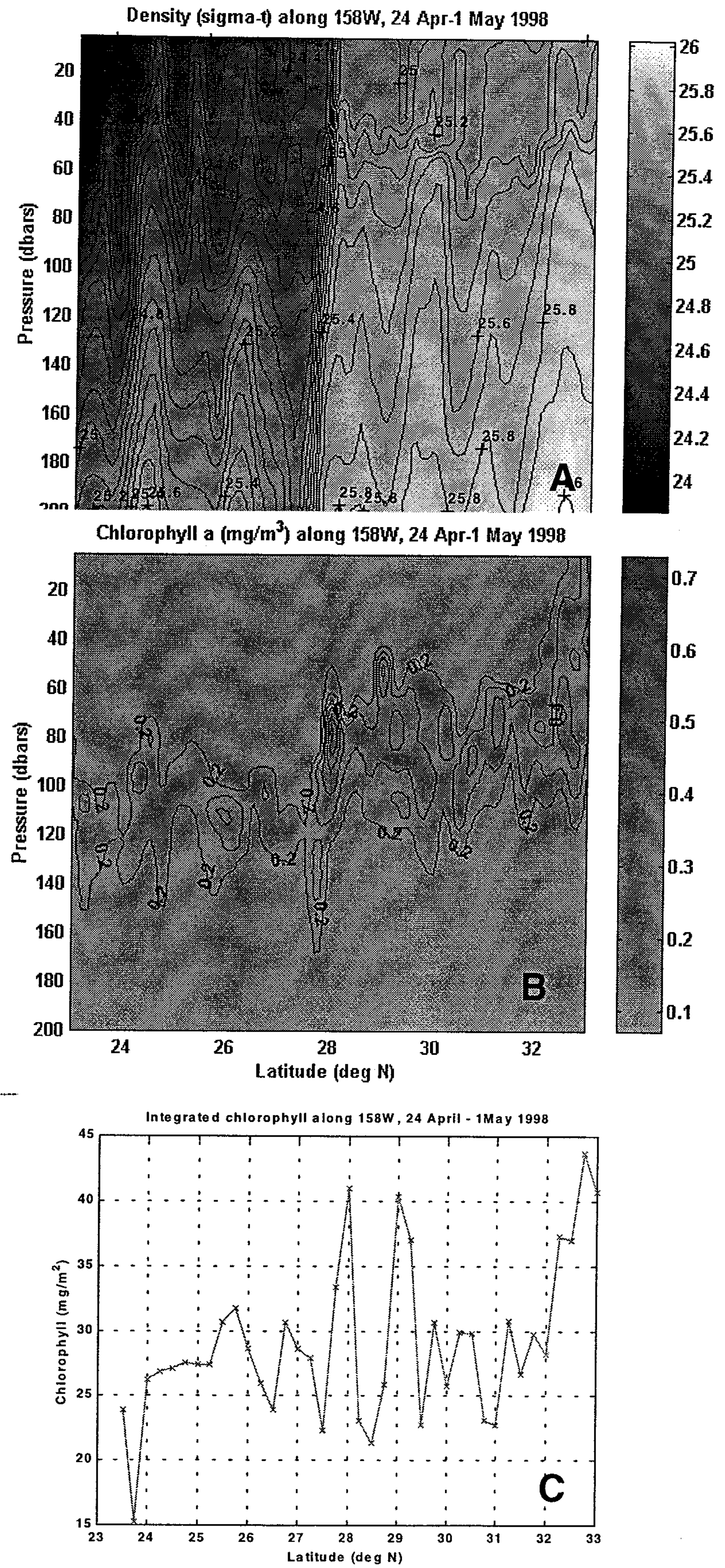

Figure 4. Meridional section of (a) density (σ_t), (b) in situ chlorophyll standing stock ($mg \cdot m^3$), and (c) integrated chlorophyll ($mg \cdot m^2$) salinity along 158°W longitude, 24 April - 1 May 1998.

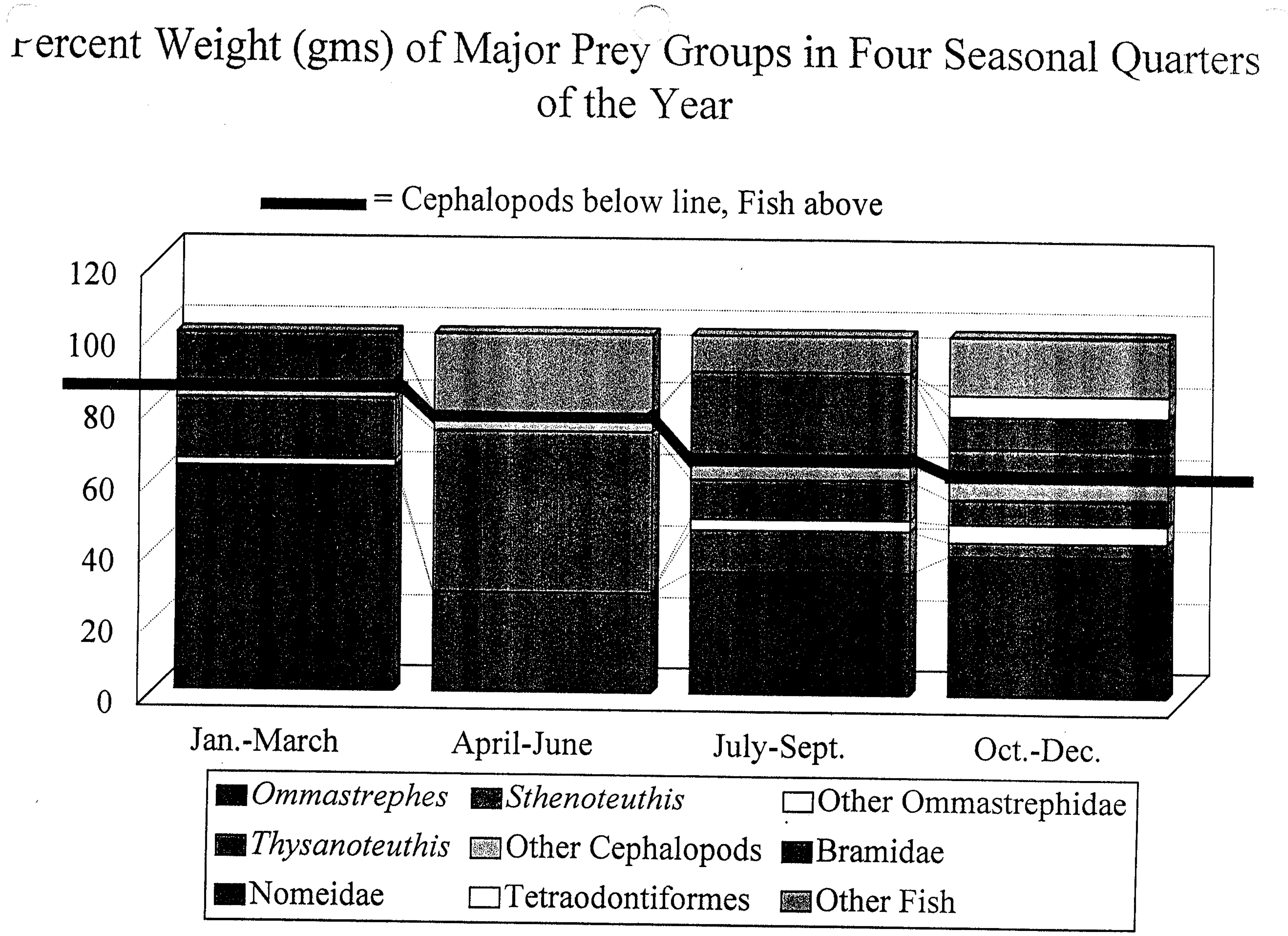

Figure 5. Aggregate percent weight (gms) of major prey groups for swordfish, *Xiphias gladius*, sampled in the central North Pacific.

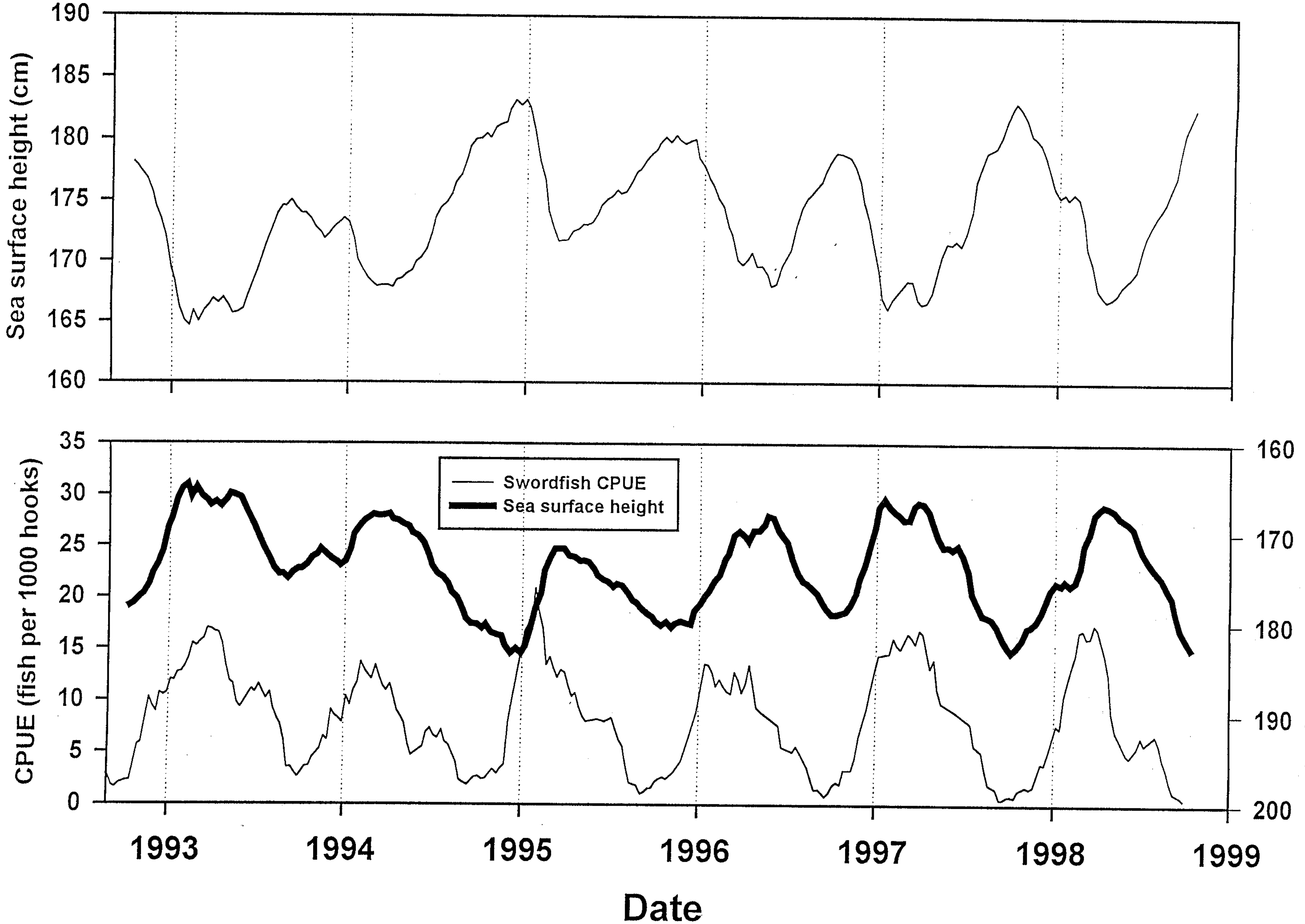

Figure 6. Top box: Mean monthly sea surface height from TOPEX/Poseidon averaged over the longline fishing ground (28-32 N, 170-150W). Bottom box: Sea surface height (reverse scale) and 5-week moving average of Hawaii-based longline CPUE for swordfish (28-32N, 170-150W).