

# Plankton populations at the bifurcation of the North Pacific Current

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## ABSTRACT

As the eastward-flowing North Pacific Current approaches the North American continent it bifurcates into the southward-flowing California Current and the northward-flowing Alaska Current. This bifurcation occurs in the south-eastern Gulf of Alaska and can vary in position. Dynamic height data from Project Argo floats have recently enabled the creation of surface circulation maps which show the likely position of the bifurcation; during 2002 it was relatively far north at  $\sim 53^\circ\text{N}$  then, during early 2003, it moved southwards to a more normal position at  $\sim 45^\circ\text{N}$ . Two ship-of-opportunity transects collecting plankton samples with a Continuous Plankton Recorder across the Gulf of Alaska were sampled seasonally during 2002 and 2003. Their position was dependent on the commercial ship's operations; however, most transects sampled across the bifurcation. We show that the oceanic plankton differed in community composition according to the current system they occurred in during spring and fall of 2002 and 2003, although winter populations were more mixed. Displacement of the plankton communities could have impacts on the plankton's reproduction and development if they use cues such as day length, and also on foraging of higher trophic-level organisms that use particular regions of the ocean if the nutritional value of the communities is different. Although we identify some indicator taxa for the Alaska and California currents, functional differences in the plankton communities on

either side of the bifurcation need to be better established to determine the impacts of bifurcation movement on the ecosystems of the north-east Pacific.

**Key words:** Alaska Current, California Current, Continuous Plankton Recorder, Gulf of Alaska, North Pacific Current, north-east Pacific, plankton, Project Argo

## INTRODUCTION

As the eastward-flowing North Pacific Current (NPC) approaches the North American continent it bifurcates into the southward-flowing California Current (CC) and the northward-flowing Alaska Current (AC) which then forms the Alaska Gyre. This bifurcation occurs in the south-eastern Gulf of Alaska (GoA) and can vary in position, although its usual latitude is at about  $45^\circ\text{N}$ . Dynamic height data from Argo floats have recently enabled the creation of surface circulation maps of the Gulf of Alaska which show the likely position of the bifurcation and its interannual variation (Freeland and Cummins, 2005).

The lower trophic level characteristics of the CC and AC along the continental slope and on the shelf have been relatively well described (Morgan *et al.*, 2003; Mackas and Coyle, 2005; Zamon and Welch, 2005 and references therein); however, the distributions of organisms related to the offshore origins of these currents is less well known and forms the focus of this paper. Two ship-of-opportunity transects collecting plankton samples with a Continuous Plankton Recorder (CPR) across the GoA were sampled seasonally during 2002 and 2003. The position of these transects was dependent on the commercial ship's operations; however most transects sampled both offshore CC and AC waters, according to the Argo-derived circulation plots. We examined the plankton data to determine whether populations were different in the two currents and assessed the effects of the bifurcation position on the distribution of planktonic organisms in the oceanic GoA.

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## METHODS

### *Circulation maps*

In this study, we used the Argo array in the GoA to explore the general circulation of the region. The Argo array is being deployed by a large international consortium and is described elsewhere (e.g. Freeland and Cummins, 2005). Freeland and Cummins (2005) demonstrated a simple and efficient method for representing the geostrophic circulation in an ocean basin by projecting computations of dynamic height, relative to a level of no motion, onto empirical orthogonal functions (EOFs) of the streamfunction field. The streamfunction field is derived from a quasi-geostrophic (CG) model of the NE Pacific described by Cummins and Lagerloef (2004). The method is straightforward and all computations can be performed in a small computer as follows:

- 1 At the site of every Argo float profile in a particular month, we compute the dynamic height at the surface relative to a reference level, usually 1000 dbars.
- 2 The mean value over 31 days (see below) is computed and subtracted from the observations to produce the first set of residuals. The mean-square

value of these residuals is the variance to be accounted for.

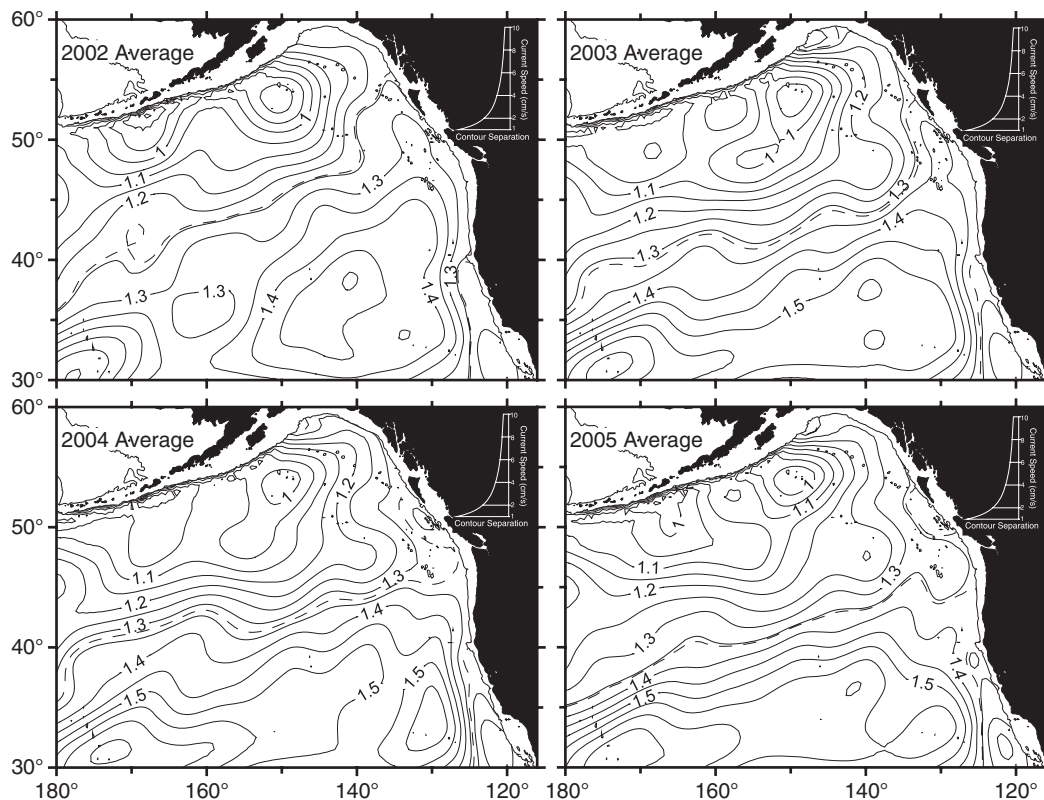
3 The best fit between the residuals and the first EOF is computed and the loading of the first EOF is stored. This weighted EOF is then subtracted from the residuals to produce a set of residuals with a smaller variance.

4 The best fit between the new residuals and the second EOF is computed, this mode is subtracted from the residuals, and so on for a total of 20 EOFs.

Although in all subsequent discussion we show circulation maps computed as 31-day averages (a central date  $\pm 15$  days) centred on the specific dates for CPR tows, Fig. 1 shows a collection of four maps representing annual averages of the circulation field. In each case the solid lines represent flow lines, analogous to isobars on a weather map. Each map shows the eastward-flowing NPC splitting into a northward branch (the AC) and a southward branch (the CC). As on weather maps the flow speed is given by the gradient of the pressure field, so when contour lines are closer together the current speeds are higher.

Although we rarely have a float actually embedded in the fast-flowing Alaska Stream (along the south

**Figure 1.** The surface dynamic height fields averaged for 2002, 2003, 2004 and 2005. The scale at top right of each map estimates current speeds from the separation of contours. The dividing streamline is indicated by dashed lines.



coast of the Aleutian Islands), this method can estimate the location and strength of this stream. This is because the flow mapping system is constrained by a physical model that does not allow ocean currents to flow into continental boundaries. The accelerating flows along the Aleutian Islands have to be present to balance the landward flows from the interior of the ocean. This technique creates a map of only the baroclinic component of the circulation, or more exactly, the flow relative to a pressure of 1000 dbars. Using the deep-float trajectories it is possible to apply essentially the same modal fitting technique to map the deep circulation from the trajectories. Freeland (2006) showed that this correction, to produce a circulation pattern relative to a level of known motion, creates changes in the circulation of the GoA that are barely discernable. The correction would be expected to be more important in other areas of the global ocean.

At some point the NPC, originating in the NW Pacific and flowing eastward, must experience a bifurcation and it is the location of this bifurcation that is of interest in this paper. The existence of a bifurcation implies that there must exist a 'dividing streamline' and these are shown on the maps as dashed lines. If the flow is steady, then any water parcel that lies to the north of the dividing streamline must eventually flow into the Alaska Gyre. Similarly, any water parcel south of the dashed line must eventually enter the CC system. A QG model of the NE Pacific was used to supply the modes used to create the circulation maps. One of the properties of a QG model is that the coastal boundary is also a line of constant streamfunction. As the dividing streamline intersects the boundary, the value of the streamfunction at the boundary must also be the value of the dividing streamline. So, the dividing streamline can be determined objectively by searching for the first constant value of the streamfunction defined over the oceans. The location of this dividing streamline is tracked over time and will be important for the remainder of this paper. Casual inspection of the maps in Fig. 1 shows evidence of massive inter-annual variation in the latitude of the bifurcation although most of the variations take place slowly over the course of several months, as shown by the maps published in Freeland and Cummins (2005). Although the low frequency variability is large, it is remarkable that there is no evidence of seasonal variability in the circulation maps.

#### *Plankton data*

Plankton samples were collected using the CPR towed behind the bulk-cargo carrier *M/V Skaubryn* on a

great circle route from British Columbia, Canada to Japan and behind the crude oil carrier *T/V Polar Alaska* on its run from Prince William Sound, Alaska to California, USA. Depth of tow was approximately 7 m in each case and ship speed averaged approximately 12.9 knots (*M/V Skaubryn*) and 15.5 knots (*T/V Polar Alaska*). Complete details of the sampling characteristics of the CPR are given in Batten *et al.* (2003) and are summarized here. Water entered through the frontal aperture of the CPR nose cone ( $1.2 \times 1.2$  cm) and was filtered by a continuously moving band of 270  $\mu$ m mesh. A second layer of mesh covered the filtered plankton with the resulting 'sandwich' rolled onto a storage spool in a tank containing ~4% buffered formaldehyde solution. The position and time of deployment, recovery, and any course changes logged by the ship were used to divide the mesh into discrete samples each representing 18.5 km of tow with a position and time assigned to the midpoint of each sample. Every fourth sample, separated by a spacing of about 55 km, was then microscopically processed and the taxonomic groups of phytoplankton and zooplankton recorded.

The level of taxonomic resolution varied according to routine CPR protocols (Batten *et al.*, 2003). For example, copepods and most hard-shelled dinoflagellates were identified to the species level while euphausiids and chaetognaths were identified to the family, or to a lower level. The CPR sampling mechanism and preservative only adequately preserves hard-shelled forms (coelenterates and athecate dinoflagellates are not identifiable from the samples) so the CPR does not sample the whole plankton community. Moreover, certain taxa are difficult to identify in CPR samples and are combined into groups (chaetognaths for example are not discriminated beyond this level). We restricted our analyses to those taxa that were highly discriminated, to genus or better, as preliminary analyses with the entire suite of taxa produced results that were more complicated to interpret.

#### *Allocation of samples to a particular current and community composition analyses*

Both transects were sampled regularly during 2002 and 2003 and often in the same month. Samples used in these analyses were restricted to those occurring south of 57°N (to avoid the influence of eddies which mix shelf and oceanic water along the south Alaskan coast), north of 43°N, west of the continental slope and east of the centre of the Alaska Gyre as defined by the Argo circulation maps. Figure 2 shows the positions of the samples used in these analyses, which provide good seasonal coverage of the oceanic GoA



(June, October and December 2002 and March/April, May/June and September/October 2003).

The transect positions were overlaid on a corresponding map of surface circulation. Monthly maps are available at [http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/argo/Dhgts\\_e.htm](http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/argo/Dhgts_e.htm) but for this study maps were generated for the midpoint of the sampling period, and if the two transects in each month were sampled more than 1 week apart a map was generated for each transect. The position of the bifurcation was noted; samples to the south-east of this position and westwards of the continental slope were denoted as CC samples while samples north-west of this position and eastwards of the centre of the Alaska Gyre were denoted as AC samples.

Community composition analyses were carried out for each separate month of sampling. The abundance of each plankton taxon in each sample was used to calculate the Bray–Curtis similarity of all possible pairwise combinations of samples (Bray and Curtis, 1957), resulting in a matrix of similarity values ranging from 0 (samples with no taxa in common) to 1 (samples with all taxa in common and with the same abundance). During routine microscopic processing of the samples, abundances are recorded into semi-logarithmic categories of abundance, e.g. a count of 15 copepods is category 5 (between 12 and 25 individuals) and a count of 35 is category 6 (between 26 and 50 individuals). As these categories represent a type of transformation that gives more weight to less abundant taxa, desired in this study, we used the category value in our analyses (from 1 to 12 for zooplankton and 1 to 10 for phytoplankton; see Batten *et al.*, 2003 for more details). One modification was that taxa that were recorded as having a ‘presence’, i.e. viewed in the sample but not in high enough abundance to be counted in the quantitative sub-sample, were given the numerical abundance of 0.1 so that they could be included in the community composition analyses. Phytoplankton and zooplankton were analysed separately.

The Bray–Curtis similarity matrix for each month was subjected to non-metric multi-dimensional scaling (MDS) analyses using the software package Systat<sup>TM</sup>. The MDS output is a two-dimensional plot of sample similarities. Samples that are the most similar are plotted closest together but the scales of the axes and the orientation of the plot are arbitrary. MDS is particularly suited for analyses where a gradient of changing community composition may be present. Plots of zooplankton and phytoplankton from each month were created and each sample coloured according to the current in which they were located (AC or CC),

defined by the Argo map, to determine whether community composition differed between currents, i.e. if the samples from each current clustered together.

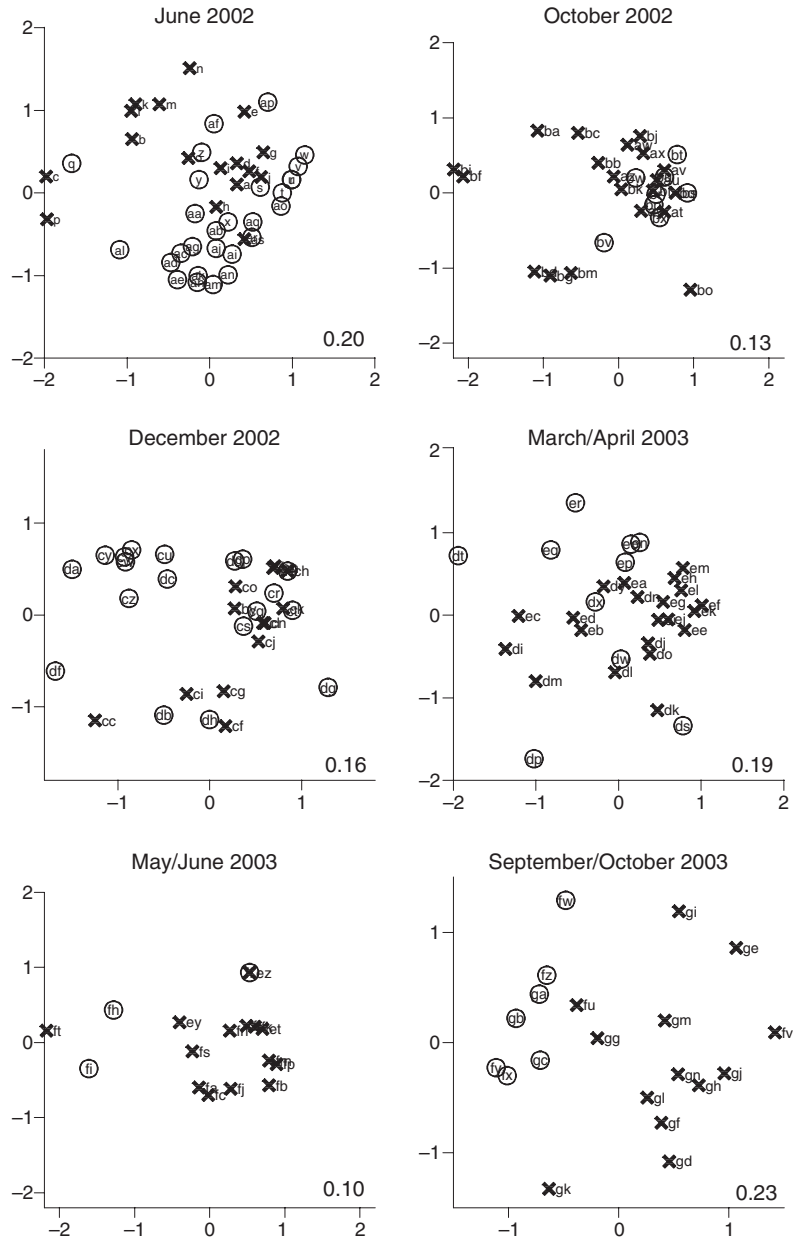
It was also possible to examine the taxa and subsequently determine which were ubiquitous throughout the GoA and which were found in either the AC or the CC. Given that the distribution of a given taxon in surface waters may change with its life history, each sampling period was treated separately.

## RESULTS

During 2002 the position of the bifurcation was relatively far north at about 53°N and then, during early 2003, it moved southwards to a more normal position (Fig 1). The plots in Fig. 2 show the location of the samples from each transect (each sample is uniquely labelled) overlaid on the corresponding Argo circulation map. Figure 3 shows the MDS output for the zooplankton analyses, and Fig. 4 the phytoplankton MDS output. Stress values for each analysis are shown in the plots. The stress value is an indication of whether a two-dimensional ordination is a useful summary of the sample relationships. Stress values above 0.3 indicate that the points are probably arbitrarily located, whereas those below 0.1 indicate a good ordination with a low chance of misleading interpretation. Stress values for these analyses are always less than 0.23 so that each plot contains useful information, though the plots with highest stress values need to be treated with caution. Note that a few samples contained no highly discriminated taxa and had to be excluded from the analyses.

Both the phytoplankton and zooplankton analyses provide the same general result in that the 2003 samples clearly show a split between samples from CC and AC waters. December 2002 and March/April 2003 analyses show no real split, which is likely because of low plankton abundances during winter (both because abundance differences are reduced and because many taxa are not present). Analyses of summer and autumn 2002 samples show some clustering or division of CC and AC samples (they tend to plot towards one side of the plot), although it is not as definite as in 2003.

In several cases, samples that are apparently within the AC (and are coloured accordingly) but are geographically close to the NPC bifurcation have a community composition more similar to CC samples (they plot near them in the MDS plot). For example, in October 2002 samples *bk*, *bl* and *bm* are apparently in the AC but their zooplankton (and to some extent the phytoplankton) samples suggest that they are more similar to those of CC waters. In June 2003 the



**Figure 3.** Results of non-metric multi-dimensional scaling analyses on zooplankton abundance data. Each sample is labelled with the same identifier and symbols are as in Fig. 2. The number in the lower right corner indicates the stress value of each analysis (see text for more details).

bifurcation occurs between samples *fe* (CC) and *es* (AC) but sample *es* clearly contains CC zooplankton (no highly discriminated phytoplankton taxa were present). Sample *fu* in Sept/Oct 2003 plots close to the CC samples in both phytoplankton and zooplankton analyses yet it lies just west of the dividing streamline and is designated as AC water.

The MDS analyses suggested that community composition differed between CC and AC waters and so individual taxa were examined and designated according to their presence in the samples; they either occurred only in CC or only in AC samples, in both or neither for each given sampling period. Table 1 lists

the taxa that were included in the analyses and their designation. There are several taxa, both phytoplankton and zooplankton, that were only found in one current throughout the sampling period and which could be used as indicators of that current (*Candacia bipinnata* and *Corycaeus* spp. are zooplankton examples in the CC, *Ceratium declinatum* a phytoplankton example from the AC) as well as taxa that seem ubiquitous throughout this region, e.g. *Calanus pacificus*, *Oithona* spp. and *Ceratium tripos*. There are also several taxa that are ubiquitous for some of the year but are then restricted to one current in other seasons. This is probably a temperature-dependent relationship; for

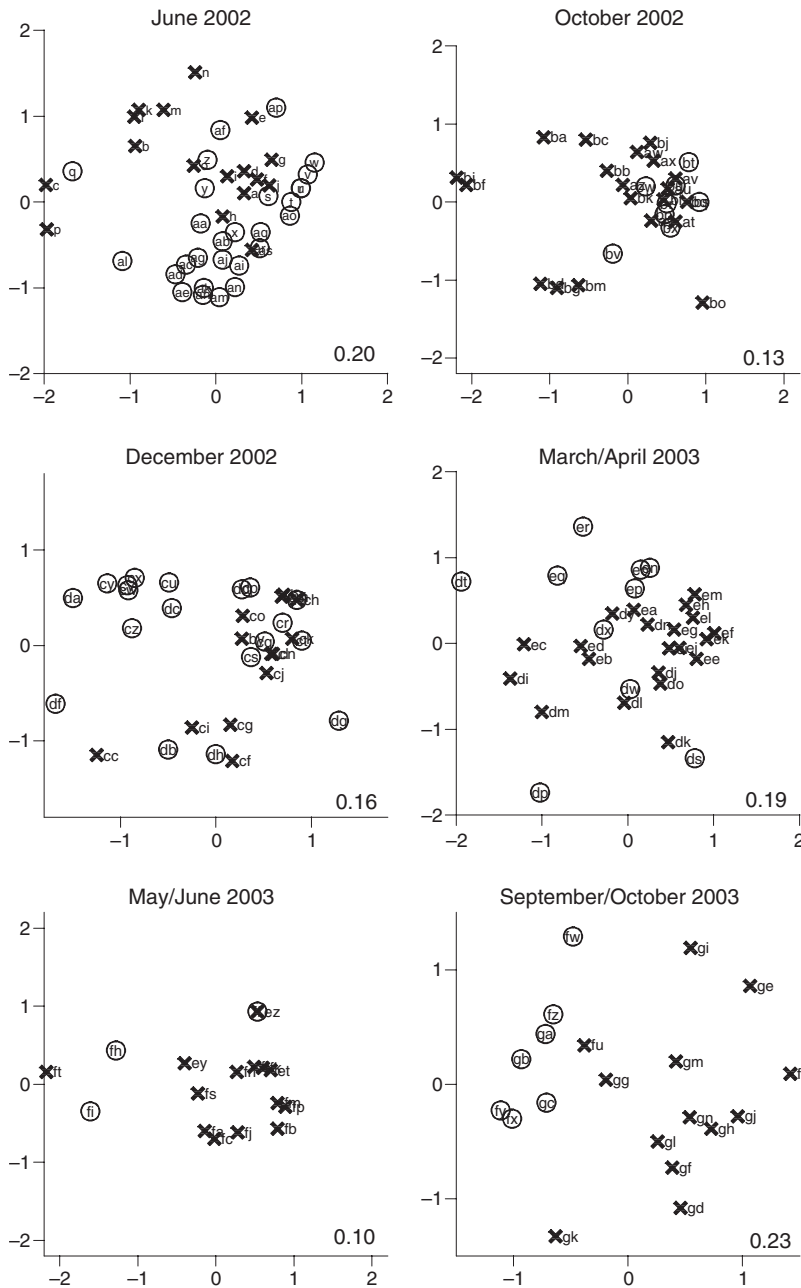


Figure 4. Results of non-metric multi-dimensional scaling analyses on phytoplankton abundance data. Each sample is labelled with the same identifier and symbols are as in Fig. 2. The number in the lower right corner indicates the stress value of each analysis (see text for more details).

example, many of the dinoflagellates of the *Ceratium* genus are AC species in the autumn (of both years) but CC species in the winter samples. This is most likely because the CC waters are warmer than the AC waters in winter and so their season is prolonged only in CC waters.

DISCUSSION

The principal aim of this study was to determine whether or not the large latitudinal movement of the

NPC bifurcation between 2002 and 2003 (by ~8° of latitude) caused a corresponding movement of associated plankton populations. By the end of our study period, when the bifurcation was at its historically more usual position, there were clear differences in the plankton communities on either side of the dividing streamline. When the bifurcation was at its most northerly, in June and October 2002, the MDS analyses produced plots somewhat less clear. Argo plots for the average conditions in 2004 and 2005 (Fig 1) show the dividing streamline inclined slightly from

**Table 1.** Taxa included in the community composition analyses (a) zooplankton, (b) phytoplankton, together with the current system in which each was found by month.

	June 2002	Oct 2002	Dec 2002	Mar 2003	June 2003	Oct 2003
(a)						
<i>Acartia danae</i>	×		○			
<i>Acartia longiremis</i>	○	×	×	■	×	
<i>Acartia</i> spp.	■	■	■	×		○
<i>Atlanta</i> spp.						○
<i>Calanus</i> spp. I–IV	■	■	■		■	×
<i>Calanus marshallae</i> V–VI	■		×	■	×	×
<i>Calanus pacificus</i> V–VI	■	■	■	■	■	■
<i>Candacia bipinnata</i>	○		○	○		
<i>Candacia colombiae</i>	×					
<i>Candacia</i> spp. I–IV	○		○	○		
<i>Centropages abdominalis</i>					×	
<i>Centropages bradyi</i>			○		○	
<i>Clausocalanus</i> spp.	■	■	■		○	■
<i>Clio</i> spp.					×	
<i>Clione limacina</i>	■			■	×	○
<i>Clytemnestra</i> spp.			○			
<i>Corycaeus</i> spp.	○		○			○
<i>Dictyocysta</i> spp.		■	■			×
Doliolidae			○	○	○	■
<i>Epilabidocera amphrites</i>			×			
<i>Eucalanus bungii</i>	○		○	■	■	×
<i>Euchirella rostrata</i>	○			○	×	
<i>Heterorhabdus tanneri</i>	×			■		
<i>Lepas nauplii</i>						■
<i>Limacina helicina</i>	■	■	■	■	×	○
<i>Lucicutia</i> spp.			○	○		○
<i>Mesocalanus tenuicornis</i>	○	○	○		○	
<i>Metridia</i> spp. I–IV	■		■	×	×	×
<i>Metridia pacifica</i>	■	■	■	■	■	×
<i>Nannocalanus minor</i>			○			
<i>Neocalanus cristatus</i> I–IV	○		■	■		
<i>Neocalanus cristatus</i> V–VI	■		×	■	■	
<i>Neocalanus plumchrus/flemingeri</i> II	×			○		
<i>Neocalanus plumchrus/flemingeri</i> III	×			■		
<i>Neocalanus plumchrus/flemingeri</i> IV	■	×	×	■	×	
<i>Neocalanus plumchrus</i> V	■			■	■	
<i>Neocalanus flemingeri</i> V	■			■	■	
<i>Oithona</i> spp.	■	■	■		■	■
<i>Oncaea</i> spp.			○			
Ostracoda			○		×	
<i>Paraeuchaeta elongata</i>	○	×		×		×
<i>Parafavella gigantea</i>	■	■	○	○		
<i>Pneumoderma</i> spp.					×	
<i>Pseudocalanus</i> spp.	■	■	■	■	■	×
<i>Ptychocylis</i> spp.				×		
Salpidae						×
<i>Sapphirina</i> spp.						■
<i>Scolecithricella</i> spp.			×	■		
<i>Tomopteris</i>	○		○	■		■
<i>Undeuchaeta bispinosa</i>	○					
<i>Zoothamnium pelagicum</i>			○			

Table 1. Continued.

	June 2002	Oct 2002	Dec 2002	Mar 2003	June 2003	Oct 2003
(b)						
<i>Asterionella glacialis</i>				○		
<i>Asteromphalus</i>	○					
<i>Bacteriastrium</i> spp.				○		○
<i>Ceratium arcticum</i>	■		×		×	
<i>Ceratium arietinum</i>			○	○		
<i>Ceratium azoricum</i>	○	■	○			
<i>Ceratium bucephalum</i>	○	■				
<i>Ceratium candelabrum</i>	○			×		
<i>Ceratium carriense</i>			○			
<i>Ceratium declinatum</i>		×		×		×
<i>Ceratium extensum</i>	○			○		
<i>Ceratium furca</i>	■	×	○	■		
<i>Ceratium fusus</i>	■	×	■	■		×
<i>Ceratium horridum</i>	○	×	○	■	×	×
<i>Ceratium lineatum</i>	○		×	■		■
<i>Ceratium longipes</i>	■	×	■	×	×	×
<i>Ceratium macroceros</i>	○		○	○		
<i>Ceratium massiliense</i>	○		○	○		
<i>Ceratium minutum</i>	○	×	○			×
<i>Ceratium pentagonum</i>	■	×	■	■	×	×
<i>Ceratium trichoceros</i>			○			
<i>Ceratium tripos</i>	■	■	■	■	×	■
<i>Chaetoceros (Hyalochaete)</i> spp.	■	■	■	×	■	■
<i>Chaetoceros (Phaeoceros)</i> spp.	■	■	■	■	×	■
<i>Cladopyxis</i> spp.		○				■
<i>Corethron criophilum</i>	■	×	■	■	×	×
<i>Dactyliosolen mediterraneus</i>	○		○			×
<i>Detonula confervacea</i>	×			×		
<i>Ditylum brightwellii</i>				○		
<i>Exuviaella</i> spp.			○			○
<i>Fragilaria</i> spp.			○			
<i>Gonyaulax</i> spp.	○	×	○	×		○
<i>Gyrosigma</i> spp.				○		
<i>Halosphaera</i> spp.	○					
<i>Hemiaulus</i> spp.	○					
<i>Lauderia borealis</i>						×
<i>Navicula planamembranacea</i>	×					
<i>Navicula</i> spp.	○		×	×		×
<i>Neodenticula seminae</i>	■	×	×	■	×	■
<i>Nitzschia delicatissima</i>	■			■		■
<i>Nitzschia seriata</i>	■	■	○	■	×	■
<i>Oscillatoria</i> spp.						○
<i>Pachysphaera</i> spp.						○
<i>Paralia sulcata</i>				×		
<i>Planktoniella sol</i>						×
<i>Polykrikos schwartzii</i> cysts				○		
<i>Proocentrum</i> spp.						■
<i>Protoperdinium</i> spp.	■	■	■	×		■
<i>Pterosperma</i> spp.	■	■	×	×	×	
<i>Rhizosolenia alata alata</i>	■	○	○	○	○	■
<i>Rhizosolenia alata curvirostris</i>		○		×		×
<i>Rhizosolenia alata indica</i>		○	○	■		×

Table 1. Continued.

	June 2002	Oct 2002	Dec 2002	Mar 2003	June 2003	Oct 2003
<i>Rhizosolenia alata inermis</i>	■		○	■		
<i>Rhizosolenia delicatula</i>	○					
<i>Rhizosolenia hebetata semispina</i>	■	○	○		■	■
<i>Rhizosolenia imbrica shrubsolei</i>	○					○
<i>Rhizosolenia setigera</i>		■				
<i>Rhizosolenia styliformis</i>	■	○	○		×	■
<i>Skeletonema costatum</i>	○					
<i>Thalassionema nitzschioides</i>	○	■	■	■	×	■
<i>Thalassiosira</i> spp.	■	■	■	■	■	■
<i>Thalassiothrix longissima</i>	■	■	■	■	×	■

×, Alaska Current; ○, California Current; ■, both.

about 42°N to 44°N between about 150° and 132°W, and then to curve sharply north to about 51°N but closer to the coast than seen in 2002/2003. If these are the 'normal' circulation conditions then almost all the samples collected in 2002 would have been in AC waters had we used the average bifurcation position, with only the most southern and eastern samples in CC waters. Taxa that were only, or predominantly, found in CC waters in the latter part of the study were also present in 2002; e.g. *Candacia bipinnata*, *Corycaeus* spp., *Mesocalanus tenuicornis*, *Ceratium macroceros* and *Ceratium massiliense*. Although they were not farther north in 2002 than in 2003, they were found in waters that would 'normally' be AC waters, according to 2004/2005 conditions. This provides some evidence that the northward movement of the bifurcation position influenced the plankton community.

Slight differences in where the Argo data suggest the bifurcation should be, and where the plankton community composition suggests it should be, could be caused by the necessary interpolation of the Argo data or the discrepancy in time between the plankton sampling and the Argo data. There are two sources of possible error in the estimation of the location of the bifurcation, or dividing streamline.

**1** The procedure used to generate the maps does not account for all of the variance in the system. The website previously identified also carries a map of expected error, which is easily computed by the estimation procedure. In the bifurcation region the expected error is typically between zero and 0.2 standard deviations, with an average of 0.1 standard deviations. For August 2005, 0.1 standard deviations is 0.019 dynamic height units, or about 0.8 of a contour interval on the plots. So, it is hard to see how the position of the dividing streamline could be varied by as much as the typical contour separation.

**2** Eddies are known to occur in the GoA, but do not exist in the QG model that lies behind the fitting process that supplies the circulation maps. However, the most intense eddies are found in the Alaska Stream and can be seen as areas of misfit in the error maps that accompany each circulation map. In the central GoA the eddies are small in horizontal extent and in height. They could cause small wiggles in the path of a streamline, but no overall change to its location.

The question arises as to whether it matters if the bifurcation moves north or south. If there is a tendency for one current to be biased towards a particular group of plankton, then the functioning of the ecosystem in certain regions of the NE Pacific could change according to the position of the NPC. This has implications for foraging animals which may go to specific oceanic regions. This study only included those taxa that are retained by the CPR and that are highly discriminated during processing and is not representative of the entire plankton community, so it is not possible to really determine functional differences from these data. Nonetheless, the warmer water copepods tend to be smaller and less lipid-rich than the sub-arctic species (Batten and Welch, 2004), and so trophic interactions and nutritional value to predators are likely to be affected by a latitudinal movement of plankton. There may also be subspecies present in each current system; Bucklin and LaJeunesse (1994) report different subspecies of *Calanus pacificus*, one associated with the central North Pacific and the West Wind Drift which is genetically distinct from the type found in the California Current off California. It may be that this distinction originates offshore and populations north and south of the dividing streamlines are genetically different and in fact it is not a single ubiquitous species in these samples.

Mackas and Coyle (2005), when considering onshore–offshore advection, ask whether organisms that rely on environmental cues may be sent confusing or conflicting signals when advected. The same issue arises here for organisms that may use day length as a cue, since an 8°N latitudinal shift would result in significant changes in day length at a given time of the year compared with what the organism is adapted to (at one extreme on the summer solstice the difference between 45°N and 53°N is 1 h 20 min of day length). Some copepods are known to use day length as an ontogenetic cue (Falkenhaus *et al.*, 1997). If north–south movements on this scale are regular occurrences then organisms are likely to have adapted to this; if they are infrequent then they could cause problems when they occur. The Argo data set extends back only to 2002 and is our best evidence for such movements, so it is too soon to say how frequently, and how far, such movements occur and whether they could provide a structuring force for NE Pacific plankton populations. At present there are also too few CPR samples for a detailed taxonomic analysis that must account for life history strategies, time of year and sample position as well as a shift in the current bifurcation. We have used a ‘weight of evidence’ approach rather than the statistical approach used with longer CPR time series as advocated, for example, in Beaugrand (2005). However, as both the CPR survey and project Argo are ongoing at this time it is hoped that further analyses will be possible.

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[www.argo.ucsd.edu](http://www.argo.ucsd.edu); <http://argo.jcommops.org/cgi-bin/WebObjects/Argo>). Argo is a pilot programme of the Global Ocean Observing System. This is NPRB publication 77.

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