Reading Scientific Literature

Continental Shelf Research 31 (2011) 1799–1810

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Phytoplankton biomass and primary production responses to physico-chemical forcing across the northeastern New Zealand continental shelf

Mark Gall *, John Zeldis

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A R T I C L E I N F O

Article history:
Received 30 August 2010
Received in revised form
24 May 2011
Accepted 6 June 2011
Available online 23 June 2011

Keywords:
Chlorophyll-*a*
Carbon uptake
Remote sensing
Integrated natural fluorescence
Depth Integration Model
Moorings

A B S T R A C T

Phytoplankton biomass and primary production were monitored in the Hauraki Gulf and on the northeastern continental shelf, New Zealand – using ship surveys, moored instruments and satellite observations (1998–2001) – capturing variability across a range of space and time scales. A depth-integrated primary production model (DIM) was used to predict integrated productivity from surface parameters, enabling regional-specific estimates from satellite data. The shelf site was dominated by pico-phytoplankton, with low chlorophyll-*a* (<1 mg m^{-3}) and annual production (136 g C m^{-2} yr^{-1}). In contrast, the gulf contained a micro/nano-phytoplankton-dominated community, with relatively high chlorophyll-*a* (>1 mg m^{-3}) and annual production (178 g C m^{-2} yr^{-1}). Biomass and productivity responded to physico-chemical factors; a combination of light, critical mixing depths and/or nutrient limitation—particularly new nitrate-N. Relatively low biomass and production was observed during 1999. This coincided with inter-annual variability in the timing and extent of upwelling- and downwelling-favourable along-shelf wind-stress, influencing the fluxes of new nitrate-N to the shelf and gulf. Relationships with the Southern Oscillation Index are also discussed. Our multi-scaled sampling highlighted details associated with stratification and de-stratification events, and deep sub-surface chlorophyll-*a* not visible to satellite sensors. This study demonstrates the importance of multi-scaled sampling in gaining estimates of regional production and its responses to physico-chemical forcing.

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ELSEVIER

CONTINENTAL SHELF RESEARCH

Title: Should give you a pretty good sense of what the paper is about – Look up words you don't know, use key-words for future searches

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ABSTRACT

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CONTINENTAL SHELF RESEARCH

Authors: Who did this work and where they work.
Useful information for future searches and context

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Typically 5 sections to look for (AIMSD):

1) Abstract

2) Introduction

3) Methods

4) Results

5) Discussion

Not meant to be read from start to finish

Skim the paper to start with to work out if this is how the paper is laid out – what are the section headings? Skim the figures, especially maps, what roughly are they doing? Is it relevant to me? Does it provide a different perspective?

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Continental Shelf Research

ELSE

Abstract

- Summary of the work
- Usually a sentence summarizing what they did and how
- Then the results and conclusions of the study
- Usually *doesn’t* include the “why should we care?”

Phyt ... o-chemical
forci

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What they did

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Implications

Main Results

A R T I C L E I N F O A B S T R A C T

Introduction

- Goal is to create interest and to get the reader to understand why they did what they did
- Includes:
  - Statement of why we should care
  - What is broadly and specifically known
  - What is *not* known or where are the important gaps in knowledge
  - What is the focus of the paper, what gaps are they going to fill
- Good place to find additional references for your own research

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1. Introduction

Continental shelf margins support greater stocks of phytoplankton biomass and primary production relative to their surface area when compared to most oceanic regions (Walsh and Dieterle, 1988; Longhurst et al., 1995). They provide key ecosystem services for fisheries and aquaculture and are receiving environments for natural and anthropogenic terrestrial inputs. An increasing appreciation of the role that continental margins play in marine carbon and nitrogen cycles prescribes a mechanistic understanding of physico-chemical environmental signals and responses to climatic patterns. The extent to which variability in biomass and production can be understood and linked to its drivers relies on the capacity to measure and model it over suitable spatial and temporal scales.

A number of models of euphotic zone primary production have been proposed and tested against observations (Behrenfeld and Falkowski, 1997a). Analyses across and between New Zealand oceanic regions (Gall et al., 1999) have demonstrated that significant proportions of variability in water column-integrated primary production can be explained primarily with knowledge of near-surface chlorophyll-*a* (chl-*a*) concentrations and photosynthetically active radiation levels. Temperature and nutrient covariates also influence this Depth-Integrated Model (DIM), but to a significantly lesser extent (Gall et al., 1999). The ability to predict euphotic zone chl-*a* from sea-surface values in the open ocean (Morel and Berthon, 1989) and to account for the majority of the variance in carbon uptake using DIMs (Behrenfeld and Falkowski, 1997b; Gall et al., 1999) has advanced our capacity to monitor primary production from satellite observations.

Sea-surface chl-*a*, measured remotely from satellite ocean colour data, show the northeastern New Zealand continental shelf (Fig. 1) to be a high primary biomass area (Murphy et al., 2001). In this region, seasonal wind-driven upwelling occurs in spring (September–November) and early summer (December), when episodic along-shelf wind-stress from the NW drives surface water offshore, transporting cool, low salinity, nitrate rich waters from depth to the surface (Zeldis et al., 2004; Zeldis, 2004). Later in summer (February), upon relaxation of upwelling favourable winds, shoreward intrusions of East Auckland Current surface water cross the shelf, infusing it with warm, high salinity, low nitrate water (Sharples, 1997; Zeldis et al., 2004; Zeldis, 2004).

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doi:10.1016/j.csr.2011.06.003

First things first: Why we should care…

1. Introduction

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Reading between the lines: This is going to be the goal of the paper

Beginning of what's already been done

1. Introduction

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First sentence of paragraph tells you what it's going to be about

A number of models of euphotic zone primary production have been proposed and tested against observations (Behrenfeld and Falkowski, 1997a). Analyses across and between New Zealand oceanic regions (Gall et al., 1999) have demonstrated that significant proportions of variability in water column-integrated primary production can be explained primarily with knowledge of near-surface chlorophyll-*a* (chl-*a*) concentrations and photosynthetically active radiation levels. Temperature and nutrient covariates also influence this Depth-Integrated Model (DIM), but to a significantly lesser extent (Gall et al., 1999). The ability to predict euphotic zone chl-*a* from sea-surface values in the open ocean (Morel and Berthon, 1989) and to account for the majority of the variance in carbon uptake using DIMs (Behrenfeld and Falkowski, 1997b; Gall et al., 1999) has advanced our capacity to monitor primary production from satellite observations.

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Introductions are usually syntheses **NOT** sequential paper descriptions

What isn't known – what are they going to do about it?

The timing and extent of upwelling and downwelling events determine the availability of nitrate for primary biomass and 'new' production (Zeldis, 2004) and affect the composition of the … 2003). Although these … ence the Hauraki Gulf … ater stratification and … play an important role …

Shifts in quasi-periodic climate states, such as the El Niño/La Niña—Southern Oscillation Index (SOI), have significant effects on the New Zealand weather; however, the pattern is a complicated one (Mullan, 1996). Although in general there is a tendency for cold southwesterlies during El Niño (upwelling favourable) and warm and moist northeasterlies during LaNiña (downwelling favourable), there are seasonal variations in this pattern (Gordon, 1986) making it difficult to correlate ecological responses and climate variability.

While the seasonal behaviour and variability of the northeast shelf system is well described, the inter-annual variability is less so. In this paper we examine phytoplankton biomass and primary production on the continental shelf and in the adjacent Hauraki Gulf coastal zone over inter-annual scales, providing the first such estimates made in this key New Zealand maritime region. The production data obtained from ship surveys over the first annual cycle are fit to a DIM and then generalised over larger time and space scales using satellite information. The resulting patterns in water column-integrated production are interpreted in context of knowledge of coincident physico-chemical properties and environmental forcing, including seasonal responses to SOI state. We discuss the efficacy of using the DIM approach in this region for obtaining synoptic measures of primary production over large time and space scales.

2. Materials and methods

2.1. Study area and sampling

Two sites were studied (Fig. 1), the first on the continental shelf (155 m) and the second in the Hauraki Gulf (40 m). Primary production was measured on the first 6 oceanographic surveys conducted from NIWA RVs *Kaharoa* and *Tangaroa*, from early spring 1998 (September) to early summer 1999 (December)—triangles in Fig. 2. The remaining seasonal ship surveys (~3 month intervals) continued baseline collections to capture three annual cycles. Water column properties were sampled using a Seabird 9/11 Plus CTD (conductivity, temperature, depth) with additional sensors for chl-*a* fluorescence (Seapoint Inc.) and scalar photosynthetically active radiation (LI-194, LI-COR Inc.), contained in a rosette sampler with 12×10-L Nisken bottles for water collections.

Sub-surface moorings at the shelf and gulf sites included internally logging thermistors (Onset Corp.) and chl-*a*-sensing, integrating natural fluorometers (INF-300, Biospherical Inc.) at approximately 15 m. At the shelf site a CT sensor (Microcat 37SM, Seabird Inc.) was also deployed near the sea bed to monitor salinity and temperature. Moorings were serviced during ship surveys. Although most instrumentation was configured to record at 10 min intervals, data were averaged into daily estimates.

Satellite sea-surface temperature (SST) data (NOAA-AVHRR) at each mooring site and along a shelf-offshore transect were extracted from the NIWA SST Archive (high-resolution (1.1 km) regional dataset—Uddstrom and Oien, 1999). Wind data from Mokohinau Island Automatic Weather Station in the centre of the study area (Fig. 1) were analysed for their along-shelf component according to the method of Zeldis et al. (2004).

2.2. Dissolved macronutrients

Dissolved macronutrients from water samples were assayed for nitrate (NO_3^-), ammonium (NH_4^+), dissolved reactive phosphorous (DRP), dissolved reactive silicate (DRSi) and total dissolved nitrogen (TDN) according to the methods of Pickmere (1998). The 'dissolved *f*-ratio'—$NO_3^- : (NO_3^- + NH_4^+)$ and the ratio of total dissolved inorganic nitrogen TDN to DRP and DRSi were calculated, to indicate the balance of new and regenerated production (Harrison et al., 1987) and potential for nutrient limitation of phytoplankton growth (Brzezinski, 1985; Redfield et al., 1963).

2.3. Chlorophyll-a

Size-fractionated chl-*a* concentrations of micro-, nano- and pico-phyto-plankton (> 20, 20–2 and < 2 μm, respectively) were determined from water samples using a filter cascade (Joint et al., 1993; Gall et al., 2001) and analysed by the fluorescence method

What we don't know (maybe a little weak in this paper…)

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What they are going to do about it

The ti… determ… 'new' … phytop… climat… coastal area further inshore (Fig. 1), freshwater stratification and nutrient input from riverine sources also play an important role (Zeldis and Smith, 1999).

Shifts in quasi periodic climate states, such as the … Niño/La …

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… - and … pico-phyto-plan… were determined fron… et al., 1993; Gall et al. … ethod

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Methods (and Materials)

- Simultaneously the most and least important part of the paper
- Most important:
    - Accurate description of what they did
    - Reproducibility of experiment
    - Allows us to assess whether results/conclusions are justified
- Least important:
    - Very detailed and technical
    - Peer reviewed so probably justified
    - Pay attention to subheadings

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Shifts in quasi-periodic climate states, such as the El Niño/La

Pay attention to subheadings and first sentences

Glean what you need and don't get bogged down in details

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First part of methods usually tells us where they went and what infrastructure they used

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Two sites were studied (Fig. 1), the first on the continental shelf (155 m) and the second in the Hauraki Gulf (40 m). Primary production was measured on the first 6 oceanographic surveys conducted from NIWA RVs *Kaharoa* and *Tangaroa*, from early spring 1998 (September) to early summer 1999 (December)—triangles in

Fig. 2. The remaining seasonal ship surveys (~3 month intervals) continued baseline collections to capture three annual cycles. Water column properties were sampled using a Seabird 9/11 Plus CTD (conductivity, temperature, depth) with additional sensors for chl-*a* fluorescence (Seapoint Inc.) and scalar photosynthetically active radiation (LI-194, LI-COR Inc.), contained in a rosette sampler with 12 × 10-L Nisken bottles for water collections.

Sub-surface moorings at the shelf and gulf sites included internally logging thermistors (Onset Corp.) and chl-*a*-sensing, integrating natural fluorometers (INF-300, Biospherical Inc.) at approximately 15 m. At the shelf site a CT sensor (Microcat 37SM, Seabird Inc.) was also deployed near the sea bed to monitor salinity and temperature. Moorings were serviced during ship surveys. Although most instrumentation was configured to record at 10 min intervals, data were averaged into daily estimates.

Satellite sea-surface temperature (SST) data (NOAA-AVHRR) at each mooring site and along a shelf-offshore transect were extracted from the NIWA SST Archive (high-resolution (1.1 km) regional dataset—Uddstrom and Oien, 1999). Wind data from Mokohinau Island Automatic Weather Station in the centre of the study area (Fig. 1) were analysed for their along-shelf component according to the method of Zeldis et al. (2004).

Maps are a great orientation tool
- Where they are measuring?
- With what tools?

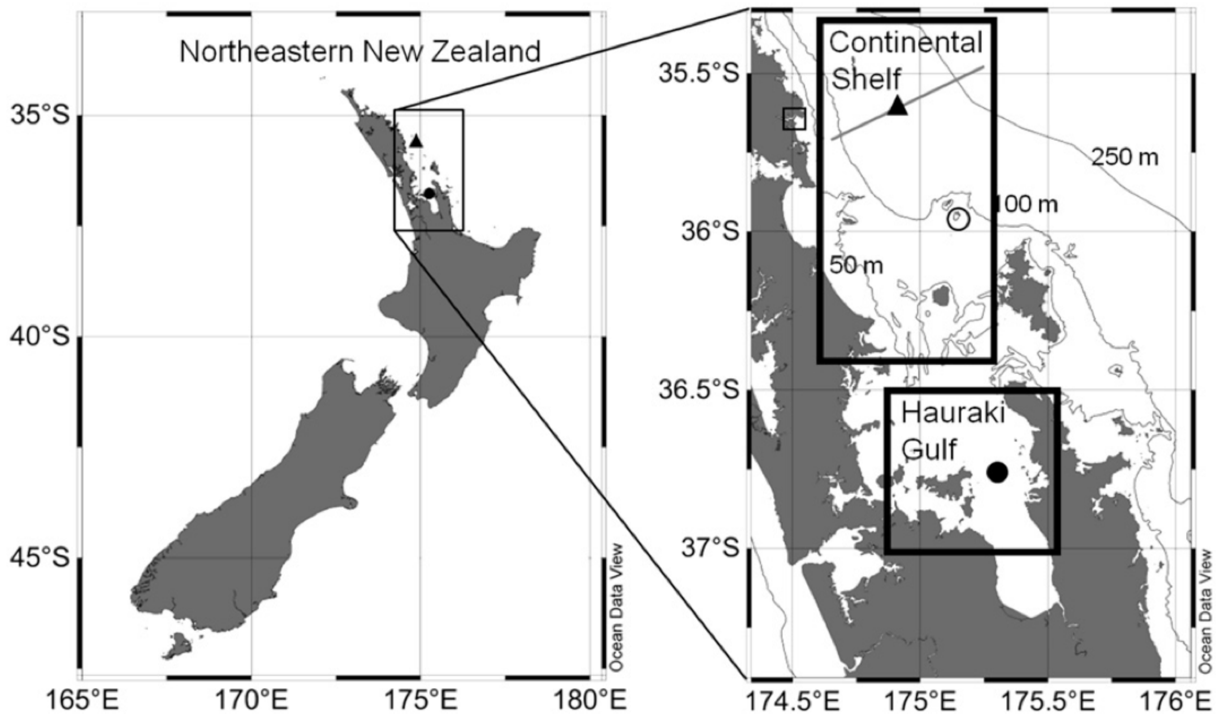


Fig. 1. Continental shelf (closed triangle) and Hauraki Gulf (closed circle) ship sampling and mooring sites, northeastern New Zealand. The open square and circle denote Whangarei airport and Mokohinau Island light and wind recording stations, respectively. Boxes indicate areas over which satellite ocean colour data were averaged. The line through the shelf site highlights the 65 km transect over which satellite SST data were sampled (see text—Fig. 12).

Figure captions should tell you everything you need to know to interpret the figure pyronometer spectrum (250–1000 nm) to PAR (350–750 nm) using manufacture-specific conversion factors (LI-COR Inc.). The euphotic zone depth (Z_e) was calculated as the depth from the surface to the depth of 1% incident light (Kirk, 1994). Sverdrup critical mixing depths (Z_c) were calculated from daily incident

Results

- What did they find using their methods?
- Figures/tables
- Accurate descriptions of data
- Often lacks interpretation or comparison to previous studies
- Some prefer it that way, some prefer to combine results with interpretations, especially when there is a sequence of logic

from the measured integrated production rates (ΣPP), day-length (DL), euphotic zone chl-*a* ($C_{surf} \times Z_e$) and the euphotic zone light dependency function fE_0 for each site (Behrenfeld and Falkowski, 1997a):

$$\Sigma PP(g\,C\,m^{-2}\,day^{-1}) = P^{b}_{opt} \times DL \times C_{surf} \times Z_e \times fE_0 \quad (3)$$

The DIM was also used with measured P^{b}_{opt} values (mean from each site) and satellite chl-*a* regional estimates—where the satellite data were corrected for positive bias when compared with ship survey water measures (see Sections 3 and 4).

3. Results

3.1. Physical and optical properties

The water column temperature and salinity structures at the continental shelf site varied significantly between 1998 and 2001

depths (Z_c) indicated light limiting conditions when mixed layer depths (Z_m) and their underlying pycnoclines (P_w) exceeded critical depths (Table 1). This occurred frequently on the shelf (e.g. early spring 1999 and 2000). At both sites critical depths reached their maxima in summer with increased light levels and water clarity, which decreased through autumn to minima during winter. In the gulf, critical depths were greater than the bottom depth from early summer to early-autumn during 1999 and 2000,

Table 1
Physical and optical properties of the water column at the shelf and gulf sites, including: mixed layer depth (Z_m, m); picnoline width (P_w, m); scalar light attenuation (K_o, m^{-1}); euphotic zone depth (Z_e, m) and sverdrup critical depth (Z_c, m).

Year/season	Date	Z_m	P_w	K_o	Z_e	Z_c
Shelf						
1998Spr	30-September-98	30	12	0.08	61	92
1998Sum	5-December-98	61	8	0.11	43	86
1999Aut	10-April-99	48	10	0.11	42	46
1999Win	12-June-99	86	23	0.09	50	36
1999Spr	17-September-99	155	0	0.11	42	63
1999Sum	14-December-99	23	13	0.07	68	156
2000Aut	09-March-00	49	40	0.13[a]	37	62
2000Win	07-July-00	ns	ns	ns	ns	ns
2000Spr	13-September-00	155	0	0.13	37	57
2000Sum	21-November-00	155	0	0.07	63	144
2001Aut	14-March-01	27	35	0.08	55	93
2001Win	11-July-01	155	0	0.05	90	68
Gulf						
1998Spr	28-September-98	19	4	0.32	15	22
1998Sum	27-November-98	9	13	0.24	20	39
1999Aut	08-April-99	40	0	0.21	22	25
1999Win	10-June-99	40	0	0.27	17	13
1999Spr	16-September-99	5	4	0.20	23	35
1999Sum	17-December-99	10	17	0.22	21	49
2000Aut	10-March-00	18	7	0.19[a]	25	41
2000Win	07-July-00	12	11	0.44[a]	11	8
2000Spr	15-September-00	19	5	0.37[a]	13	19
2000Sum	04-December-00	28	2	0.23	20	46
2001Aut	10-March-01	23	3	0.15	31	52
2001Win	11-July-01	17	3	0.19	25	19
Shelf		**86**	**13**	**0.09**	**53**	**82**
Gulf		**20**	**6**	**0.23**	**20**	**31**

ns—not sampled.
Note that southern hemisphere seasons are defined broadly here as: spring (September–November), summer (December–February), autumn (March–May) and winter (June–August).

[a] Due to poor light profiles or missing data, values have been estimated from a surface chl-*a* to attenuation relationship (Fig. 10).

The water column temperature and salinity structures at the continental shelf site varied significantly between 1998 and 2001

(Fig. 2a and b). During summer–autumn 1999 (January–March) surface waters were warmer than other years. Temperatures and salinities of deep water during spring 1999 (August–October) were higher than other years, especially 1998, indicating different water mass types (Fig. 2b).

Although the gulf site displayed similar overall patterns in thermal structure compared with surface shelf waters (Fig. 2c), there were some notable differences. This relatively shallow site was more often thermally de-stratified, completely mixing to the bottom during late-summer 1999 (January) and mid-late autumn (February–April), early-winter (March) and early-spring (August) in all years. The strength, extent and timing of stratification varied inter-annually, being particularly weak in summer–autumn 1999. The occurrence of winter temperature stratification with cool water in the upper water column (particularly during 1999) was a consequence of low salinity waters from rivers, enabling buoyant (yet cold) surface waters (evident in vertical CTD profiles—data not shown).

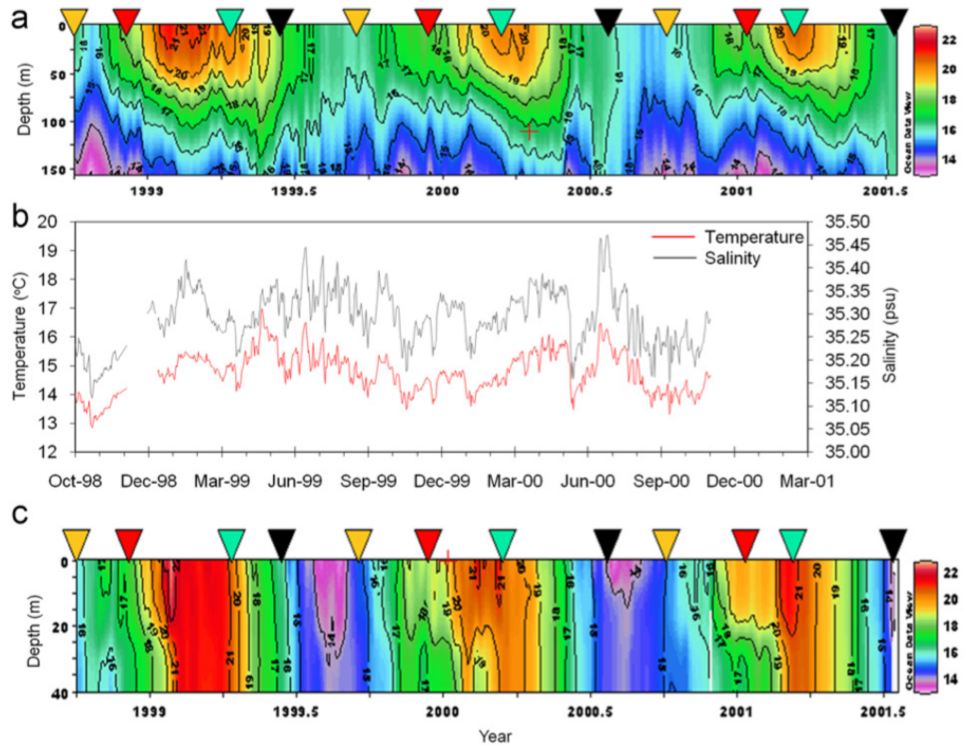


Fig. 2. Water column isotherms at the continental shelf (a) and Hauraki Gulf (c) sites. (b) Shelf temperature and salinity records measured near the sea-bed (150 m). Note the depth scale difference between shelf and gulf sites. Triangles indicate seasonal ship surveys (orange—spring, red—summer, green—autumn and black—winter).

Are the descriptions good? Do you agree?

Think about what you want to know, not just what they are trying to tell you…

e.g. this figure might give you some idea of the typical values and structures you might see and how they change over time…

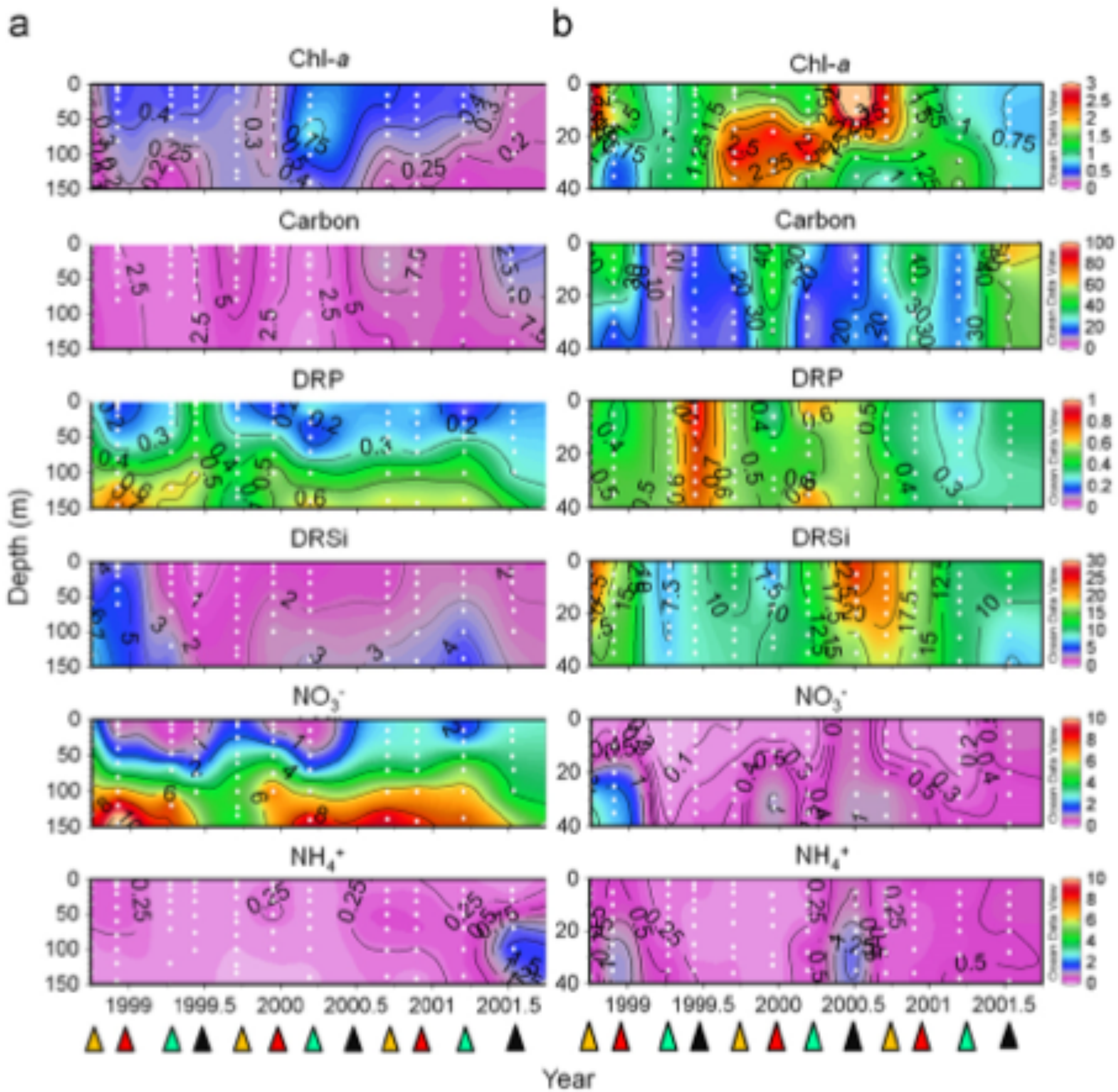


Fig. 3. Continental shelf (a) and Hauraki Gulf, (b) seasonal water column concentrations of phytoplankton chl-*a* (mg m^{-3}), carbon (mg m^{-3}) and nut
[dissolved reactive phosphorus (DRP), dissolved reactive silicate (DRSi), nitrate (NO_3^-) and ammonium (NH_4^+)]. *Note:* Winter 2000 data for the shelf wa

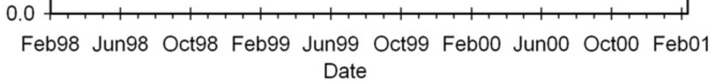


Fig. 7. Monthly averaged satellite chl-*a* concentration (mg m^{-3}) measured within areas encompassing the shelf (a) and gulf (b) sites (boxes in Fig. 1). Inset images

Discussion

- what they interpret their results to mean
- Any caveats or places where they need to justify their interpretations
- Should seek to provide the answer to the question(s) posed in the introduction
- Again, pay attention to subheadings if they exist
- Typically you don't introduce any new results in the discussion…

Fig. 8. Least-squares relationships of column-integrated C:chl-*a* to chl-*a* for shelf and gulf sites. Data values include a pico-phytoplankton C estimate of 5 mg C m^{-3} (see text).

for more variability in *C*:chl-*a* ($r^2 = 0.72$, $n = 11$) than for the gulf ($r^2 = 0.25$, $n = 12$).

3.5. *Primary production*

Total areal phytoplankton C uptake rates were higher in the gulf than on the shelf on all occasions except winter 1999 (Table 3). Areal C uptake was predominantly in the micro-phytoplankton size fraction in the gulf and pico-phytoplankton fraction at the shelf, with similar rates for nano-phytoplankton in both regions. Thus, patterns in the proportion of C uptake in

relationship was found, explaining about half the variability [predicted = 0.96 × observed + 95, $r^2 = 0.496$, $n = 11$, $p < 0.05$]—Fig. 9. In order to extend areal C uptake in space and time using the DIM construct, we require estimates of euphotic zone depth (Z_e) from surface chl-*a*. Water column light attenuation (K_o) was strongly correlated to surface chl-*a* ($\mathrm{Chl_{surf}}$) from ship samplings ([$K_o = 0.093 \times \mathrm{Chl_{surf}^{2/3}} + 0.049 \times \mathrm{Chl_{surf}} + 0.04$, $r^2 = 0.950$, $n = 19$, $p < 0.01$]—Fig. 10). Monthly averaged SeaWiFs time series SAT chl-*a* concentrations for each region (Fig. 7) were used to estimate K_o and therefore euphotic zone depths. The euphotic zone depths so obtained were combined with monthly averaged SAT chl-*a* concentrations for each region (Fig. 7), their mean P^{b}_{opt} estimates above and light dependency (fE_o) values (0.56 for both regions: Table 3), to calculate areal C uptake for each region over the time series (Fig. 11). This showed typical annual production-light intensity cycles, but also inter-annual variation, with lower production in shelf and gulf regions during 1999, particularly in spring. Production was uniformly higher in the gulf than on the shelf.

4. Discussion

In this paper primary production values collected at two sites – on the northeastern continental shelf and in the Hauraki Gulf, New Zealand – were used in a depth-integrated model (DIM) to predict column-integrated production from surface-sensible variables (i.e. chl-*a* and light). This was similar to the strategy used by Gall et al. (1999) in New Zealand open ocean waters and represents the first such application in a coastal zone in New Zealand. The findings were compared with coincident physico-chemical sampling from ship surveys, moorings and satellite observations made over three years, to enable a broadened perspective on production dynamics over seasonal to inter-annual time scales across this high-value maritime region.

4.1. *Estimating phytoplankton biomass from chl-a and carbon*

To examine the validity of the DIM approach, we must consider first how well we estimate surface chl-*a*, how well surface chl-*a* represents integrated euphotic zone chl-*a* and finally how well these predict integrated phytoplankton carbon. Satellite chl-*a* overestimated ship-derived values by 1.4 (Fig. 5), but was otherwise well correlated with *in-situ* values. The positive bias was expected for the

This paper clearly does introduce new results – like this result that shows that the winds can be used to explain the temperature record

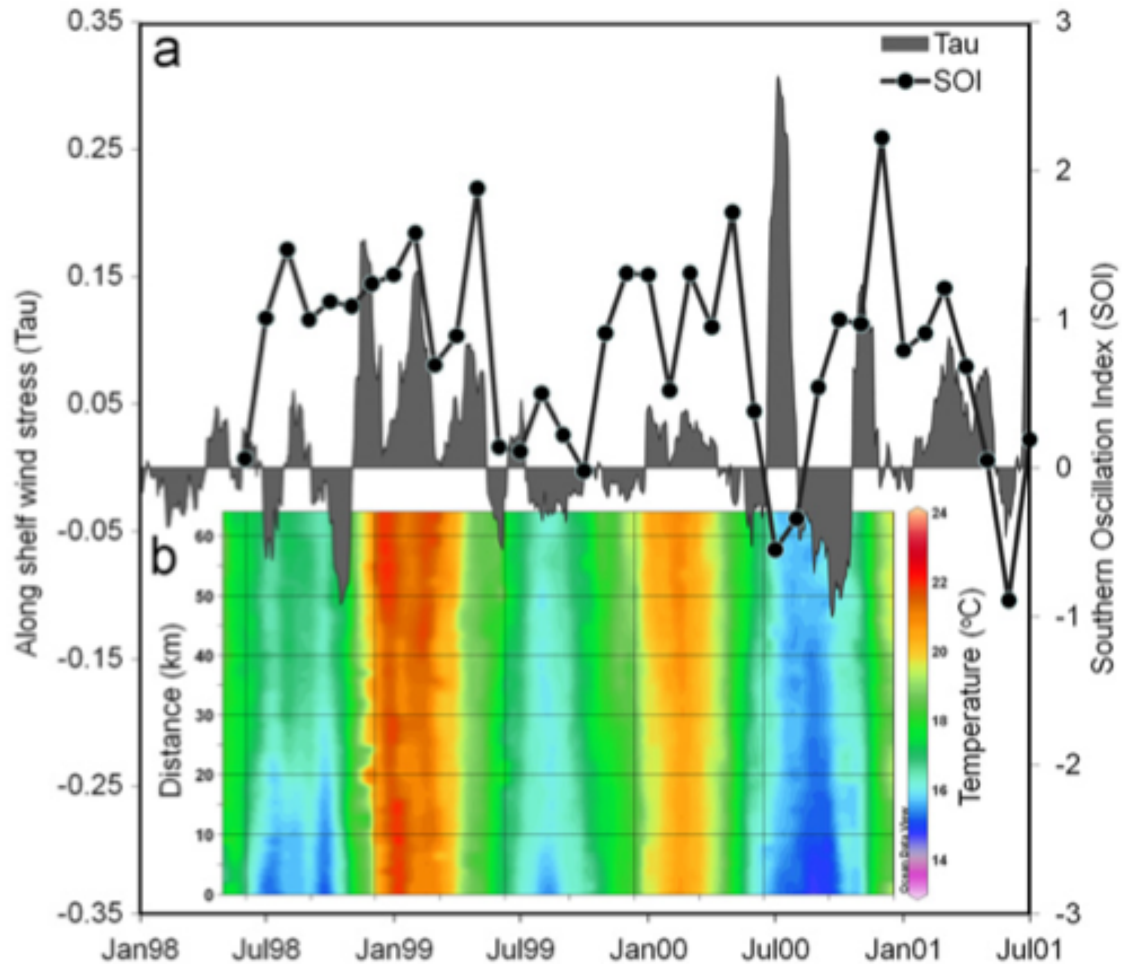
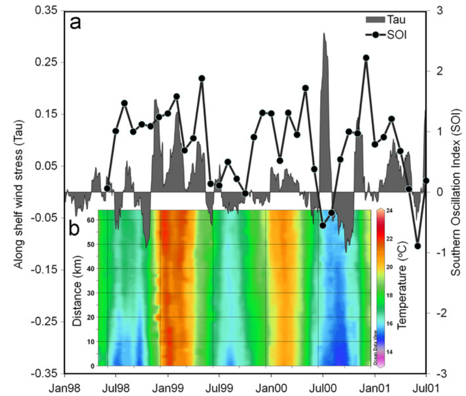


Fig. 12. (a) Along-shelf wind-stress from winter 1998 to winter 2000 showing northwesterly (negative) wind-stress in winter and spring 1998 and 2000 and southeasterly (positive) wind-stress during summer, autumn and winter of 1999. Values (circles) of the Southern Oscillation Index (SOI) also shown. (b) Satellite sea-surface temperature (SST) plotted in cross-shelf distance-by-time space (transect in Fig. 1). Upwelling fronts are shown by the more intense cool signatures and onshore/offshore contrasts in SST in winter–spring 1998 and 2000 during upwelling-favourable winds (refer a). These features were absent in winter–spring 1999, following the extended downwelling favourable southeast wind-stress period.

Always zip to the end of the discussion to see if there're a general conclusions…



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The Southern Oscillation Index (SOI) was largely positive (La Niña) through both the upwelling-favourable NW wind periods in winter–spring 1998 and 2000, and the downwelling-favourable SE wind periods in summer, autumn and winter of 1999 (Fig. 12a). It was therefore not temporally correlated with the pattern of along-shelf wind-stress across our study interval. This was perhaps surprising, given that westerly conditions are often correlated with El Niño in New Zealand (Gordon, 1986; Mullan, 1995). Explaining this finding is that the correlation of wind-stress in the along-shelf (NW-SE) direction to SOI state is known to be strong only in the summer trimester (December–February: Gordon, 1986; Zeldis et al., 2008), with much weaker correlations in the spring and autumn trimesters, and no correlation in the winter trimester. Thus we can expect to see, over longer time frames, a consistent relationship between SOI state, along-shelf wind-stress and upwelling/downwelling effects on biomass and production in summer, but weaker or non-existent relationships outside of that period. Other analyses, primarily of longer SAT chl-*a* timeseries are required to further our understanding of relationships of primary biomass and production in this region with climate variability.

4.4. Conclusion

A regionally calibrated depth-integrated primary production model, the first for a New Zealand coastal area, was used to predict integrated productivity in the important northeastern maritime region using surface-sensible parameters and knowledge of P^{b}_{opt}. The results show similar peak integrated production rates between shelf and gulf sites, driven by greater euphotic depths on the shelf but lower surface chl-*a* values there than in the gulf. Varying rates of primary production between years were also shown, dependent on up- and down-welling conditions, reflecting effects on the rate of new NO_3^- supply (Zeldis et al., 2004), resultant nutrient-limiting conditions and effects on mixing and critical depths. The DIM thus predicted a considerably less productive euphotic water column under downwelling conditions. The effect was strongest on the shelf, near the site of wind-driven upwelling/downwelling dynamics (Zeldis et al., 2004) as opposed to the gulf, where river inputs also affect nutrient loading and stratification and where benthic-remineralised nutrient supply may buffer new N variations (Zeldis et al., 2004; Giles et al., 2007; Zeldis et al., 2010). Thus, the inter-annual variations in productivity shown by the DIM were consistent with the known effects of the underlying environmental forcing on nutrient supply, confirming its use in explaining variation in the resulting biogeochemical fluxes. This study also demonstrated the importance of synoptic, up-scaled information combining ship surveys, moorings and remote sensing, in gaining estimates of regional production and its responses to physico-chemical forcing.

Acknowledgements

Contribution from scientific staff and masters and crews on the RV *Kaharoa* and RV *Tangaroa* (NIWA) is much appreciated. Karl Safi provided phytoplankton identification and advice. Ken Richardson supplied the ocean colour remote sensing data. Kathy Walter extracted wind data. Kevin McGill provided sea-surface temperature from the NIWA AVHRR Remote Sensing Archive. Jill Schwarz provided review advice in the completion of this manuscript. The work was funded by the Foundation for Research Science and Technology "Coasts and Oceans Outcome-Based Investment" (Contract no. C01X0501).

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The Southern Oscillation Index (SOI) was largely positive

References:
- A great place to find additional sources or look up what the authors were talking about

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A regionally calibrated depth-integrated primary production model, the first for a New Zealand coastal area, was used to predict integrated productivity in the important northeastern maritime region using surface-sensible parameters and knowledge of P^{b}_{opt}. The results show similar peak integrated production rates between shelf and gulf sites, driven by greater euphotic depths on the shelf but lower surface chl-*a* values there than in the gulf. Varying rates of primary production between years were also shown, dependent on up- and down-welling conditions, reflecting effects on the rate of new NO_3^- supply (Zeldis et al., 2004), resultant nutrient-limiting conditions and effects on mixing and critical depths. The DIM thus

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