

Appendix – Remote Sensing

Using remote sensing to determine estimates of secondary production

Introduction

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched in September 1997 to provide quantitative data on global ocean bio-optical properties to the Earth science community. Using ratios of the water leaving radiance SeaWiFS imagery can be used to quantify properties such as the chlorophyll concentration (O'Reilly *et al.*, 1998). Algorithms have been developed to use the surface chlorophyll concentration detected by the satellite to allow an estimate of the phytoplankton primary production to be made (Joint and Groom, 2000). It is a logical progression to therefore search for methodologies which use satellite data to provide estimates of secondary production. The copepod egg production model of Prestidge *et al.* (1995) provides such a medium. For the purposes of the Shelf Edge Advection Mortality And Recruitment (SEAMAR) project, this model, which was originally developed for use in the Irish Sea, was extended to cover the entire SEAMAR model domain (see figure 1). The model uses as input sea surface temperature (SST) and chlorophyll data to produce a species specific egg production (EP) rate; this is assumed to depend exponentially on temperature and to have a Michaelis-Menten relationship with the food concentration.

$$EP = \begin{cases} Z_0 \exp\{(T - 10)/\theta\} \frac{P(t) - P_0}{P(t) + P_h} & \text{when } P(t) > P_0 \\ 0.0 & \text{otherwise} \end{cases} \quad (1)$$

where Z_0 =maximum egg production rate at 10°C, T =surface temperature, θ =temperature coefficient, P =surface phytoplankton concentration, P_0 =threshold phytoplankton concentration, P_h = half-saturation phytoplankton concentration. The model can be run for different copepod species by changing the parameters Z_0 , θ , P_0 , and P_h . Full details of the parametrisations can be found in Prestidge *et al.* (1995).

Method

The model has been developed to use SST and chlorophyll data from monthly mean satellite retrievals of both parameters: Advanced Very High Resolution (AVHRR) satellites for the SST and SeaWiFS for chlorophyll (surface phytoplankton concentration). Mean monthly maps of SST (NASA Pathfinder project) and chlorophyll for 1998 covering the SEAMAR model domain can be seen in figure 2. 1998 was chosen as it coincided with the latest ICES triennial survey. The SST monthly maps show a gradual warming trend as the seasons progress, which is to be expected. Areas of persistent cloud and land are masked out in black. The corresponding chlorophyll images show a generalised maximum in the chlorophyll concentration over the model domain in May which coincides with the spring bloom. The Bay of Biscay shows lower values of chlorophyll during the summer months that during February / March. Higher values of chlorophyll (2 – 3 mgm^{-3}) occur off the shelf break between May and August in the Atlantic between 50 and 55°N. Outside of

this period most of the phytoplankton are confined to the shelf region. However a note of caution must be sounded here as some of the apparently high concentrations of chlorophyll could be caused by sediment loading especially in regions close to riverine outflow. This causes an error in the chlorophyll algorithm which in turn will lead to an overestimate of the secondary production. In deep oceanic waters however there can be a high degree of confidence placed in the chlorophyll concentration satellite retrieval and hence the estimate of secondary production will be made using realistic figures.

The model parameters were initially set to those of *Calanus* and *Acartia*; although the model can be run for other species of copepod. It is thought that these two species make up the majority of the secondary production relevant for the study of *Scomber scombrus*, the species of mackerel being studied in the North East Atlantic for the SEAMAR project. The output of the model, shown in figure 3 for the example of *Calanus*, is in units of number of eggs per female per day and as such represents a potential for egg production. Figure 3 shows that the highest potential for egg production in the Bay of Biscay occurs in February and March with any egg production being confined to the narrow shelf region after that. February to April mark the time where the shelf plays a dominant role; from May through to August the deep oceanic waters give an enhanced pattern of potential egg production. However, these values are meaningless for the retrieval of secondary production and purely reflect the background environmental conditions of the top few metres of the water column. To obtain useful values the model output needs to be multiplied by the number of female copepods of the species present at a particular grid point. Such data can be obtained from the Continuous Plankton Recorder (CPR) survey. CPR data from 1998 for the species *Calanus helgolandicus* + *finmarchicus* and *Acartia clausii* were used to construct a weighting function for each respective species; figure 4 shows the distribution of *C. hel* + *fin* (stage V and VI) measured by the CPR during the months of 1998. Assuming a female to male ratio of 2:1 and a stage V (adult) to stage VI (mature adult) ratio also of 2:1 gives a factor of 0.22 to multiply the CPR data by to get the number of *C. hel* + *fin* mature adult females. For *A. clausii* a factor of 0.5 is used as a male:female ratio of 1:1 is assumed. To convert the CPR multiplied data into units of $\text{ngCl}^{-1}\text{d}^{-1}$ account needs to be taken of the weight of carbon the species egg represents. This is 360 and 30ngC for *Calanus* and *Acartia* respectively. This gives units of $\text{ngC}(3\text{m})^{-3}\text{d}^{-1}$, and to therefore convert to units of l^{-1} these figures are divided by 3000. The whole modelling procedure is shown schematically in figure 5, starting with an input of SST and chlorophyll and ending up with monthly maps of secondary production.

Results

Figure 6 shows the secondary production results in terms of a weight of carbon per litre per day for both *Acartia* and *Calanus*. There is a marked seasonal cycle for both species of copepod, this being largely determined by the chlorophyll. In winter (February and March) there are low values of production ($<2\text{ngCl}^{-1}\text{d}^{-1}$) and activity is confined mainly to the shelf region. In April and May there is a migration of the copepods off the shelf break, which is shown in the CPR data for *Calanus* in figure 4, and an increase in the values of production to between 30 – 100 $\text{ngCl}^{-1}\text{d}^{-1}$ which coincides with the spring phytoplankton bloom. In the *Calanus* maps of figure 6 there seems to be a general relaxation of the secondary production and a migration back to the confines of the shelf during the late summer. This is particularly marked in the

Western Approaches with a sharp cut-off in the secondary production over the Goban Spur in August and September. This step function over the shelf break in this region is also marked in the *Acartia* maps for the summer months. However there is an increase in secondary production over the model domain as a whole during the summer. The distribution of *Acartia* is more widespread and with generally higher values of secondary production over the model domain. This is particularly pronounced in the summer months and at high latitudes.

Model validation

There are two approaches to validate the model output. The first approach uses estimates of primary production and assumes a 10% incorporation into secondary production. The second uses estimates of the CPR summer biomass and the associated grazing requirements, again assuming a 10% incorporation. Taking the Western Approaches to be the validation area the values of secondary production range between $16 - 35 \text{ ngCl}^{-1} \text{ d}^{-1}$ for *Calanus* and $6 - 15 \text{ ngCl}^{-1} \text{ d}^{-1}$ for *Acartia*. Changing this to units of $\text{mgCm}^{-3} \text{ d}^{-1}$ this corresponds to $0.016 - 0.035 \text{ mgCm}^{-3} \text{ d}^{-1}$ and $0.006 - 0.015 \text{ mgCm}^{-3} \text{ d}^{-1}$ respectively.

i) Primary production approach

Joint et al. (2000) calculated for this shelf edge region that primary production was approximately $16 \text{ mgCm}^{-3} \text{ d}^{-1}$. Assuming a 10% efficiency transfer to mesozooplankton this gives $1.6 \text{ mgCm}^{-3} \text{ d}^{-1}$. If *Calanus* makes up between 10 – 35% and *Acartia* 1 – 3% of the biomass this gives species specific secondary production to be between $0.16 - 0.56 \text{ mgCm}^{-3} \text{ d}^{-1}$ for *Calanus* and $0.016 - 0.048 \text{ mgCm}^{-3} \text{ d}^{-1}$ for *Acartia*.

ii) Biomass approach

The CPR summer biomass was found to be 3 mgCm^{-3} , corresponding to a grazing requirement of $5 \text{ mgCm}^{-3} \text{ d}^{-1}$. Assuming a 10% incorporation rate and the same percentage biomass contributions as above results in species specific secondary production to be between $0.05 - 0.18 \text{ mgCm}^{-3} \text{ d}^{-1}$ for *Calanus* and $0.005 - 0.015 \text{ mgCm}^{-3} \text{ d}^{-1}$ for *Acartia*. There is a factor of three difference in the two different approaches which provides a range for comparison with the model output.

Comparison with the model output

i) Calanus

The *Calanus* modelled output gives a range of secondary production between 0.016 and $0.035 \text{ mgCm}^{-3} \text{ d}^{-1}$ which is about 5 – 10% of that predicted using the primary production approach and 20 – 30% of that for the biomass approach. The error is unlikely to be because of the assumptions made in terms of the ratio of male to female copepods. At present the reason for the discrepancy is not known.

ii) Acartia

The *Acartia* modelled output gives a range of secondary production in the Western Approaches to be between $0.006 - 0.015 \text{ mgCm}^{-3} \text{ d}^{-1}$ which is almost precisely that predicted using the biomass approach and 30 – 40% of that for the primary production approach. This is an encouraging result and suggests that, for *Acartia* in the Western Approaches at least, the model is producing valid results.

Conclusions

The model of Prestidge *et al.* has shown itself to provide stable results when satellite data over a large spatial area is provided as input. The results give realistic values of the rate of copepod egg production over the entire model domain for the two species tested in this study. When the model output is weighted using CPR data to obtain estimates of secondary production the values for *Calanus* are only between 5 – 30% of that expected using primary production and biomass calculations. When *Acartia* is considered there is a high degree of agreement between the modelled and the two calculation approaches. The results suggest that more work is required on the modelling approach especially where *Calanus* is considered. This species is particularly important as it makes up a large percentage (10 – 35%) of the planktonic biomass. During the next six months work will progress on improving the model and consequently improving its output.

References

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- Joint I.R. et al (2001) Pelagic production at the Celtic Sea Shelf Break – the OMEX I project. *Deep Sea Research* *In press*
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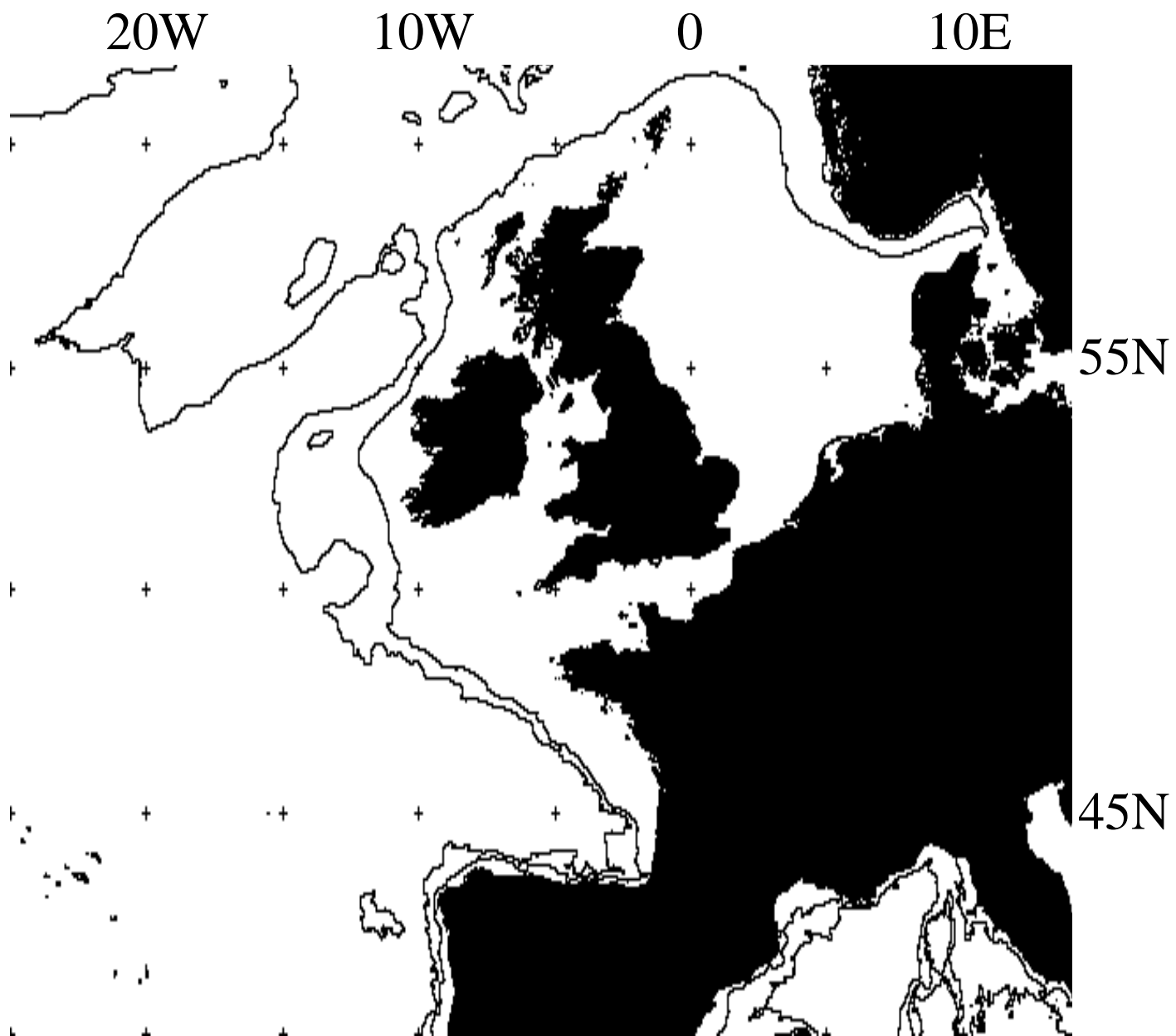
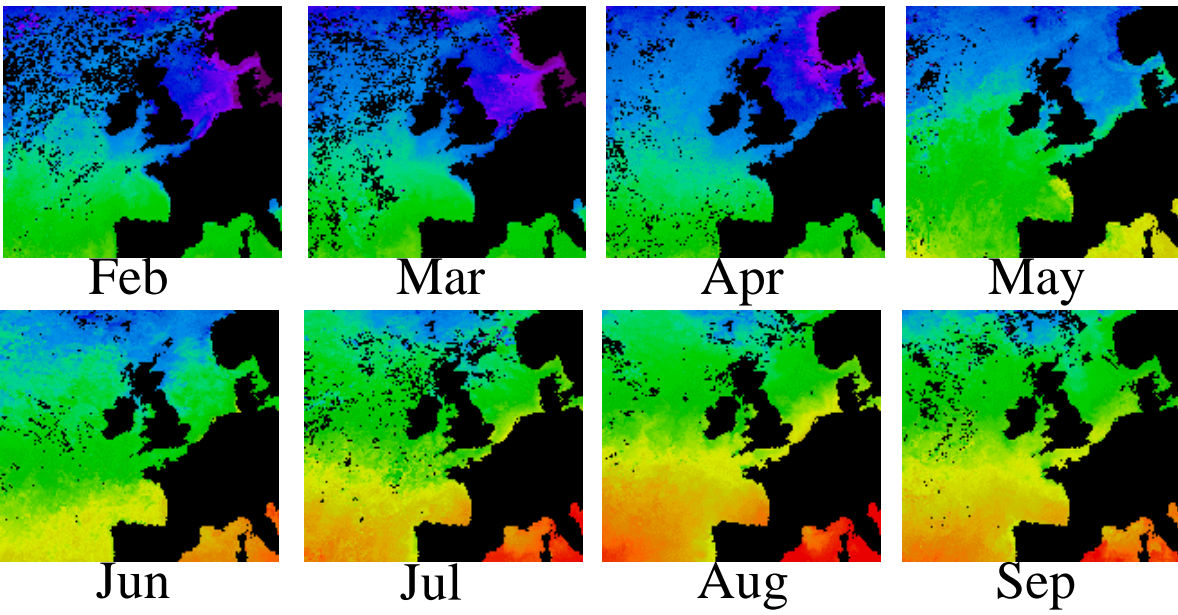


Figure 1: SEAMAR model domain. Bathymetry shows 200 and 2000m contours

SST



Chlorophyll

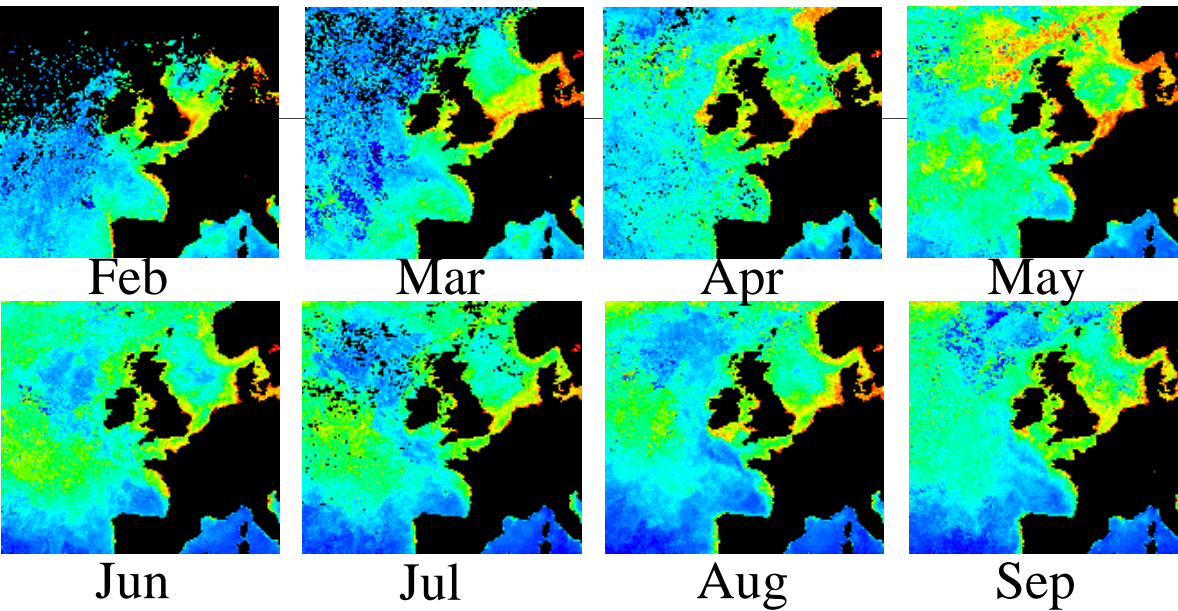
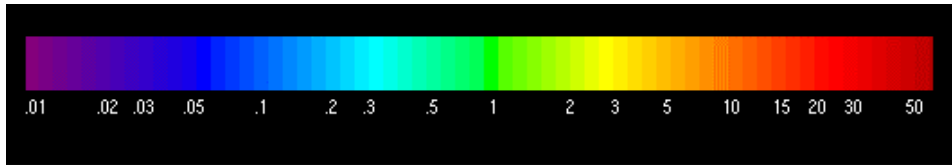


Figure 2: Monthly SST and chlorophyll maps for 1998 covering the SEAMAR model domain

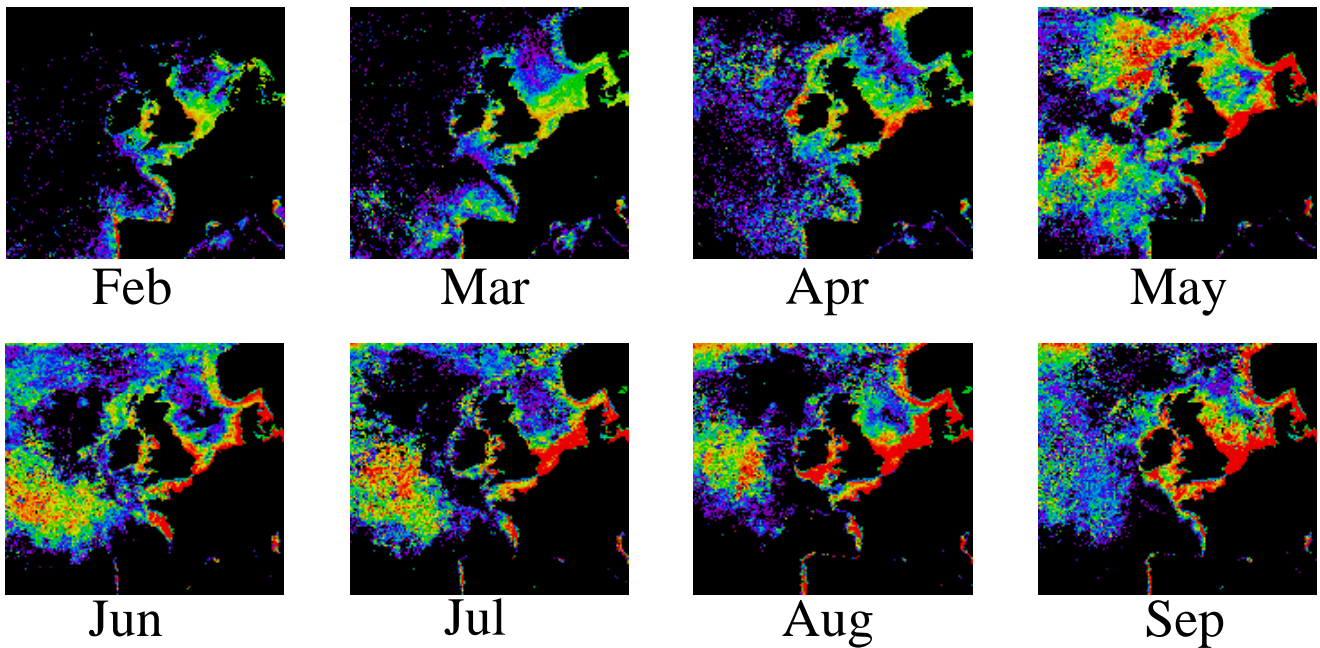
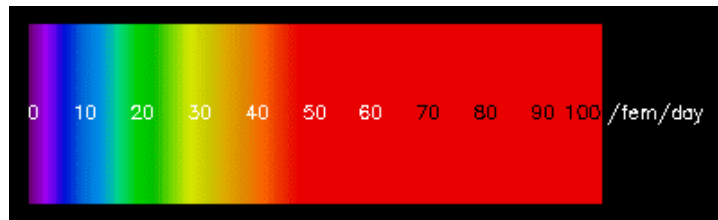


Figure 3: Prestidge model output for Calanus

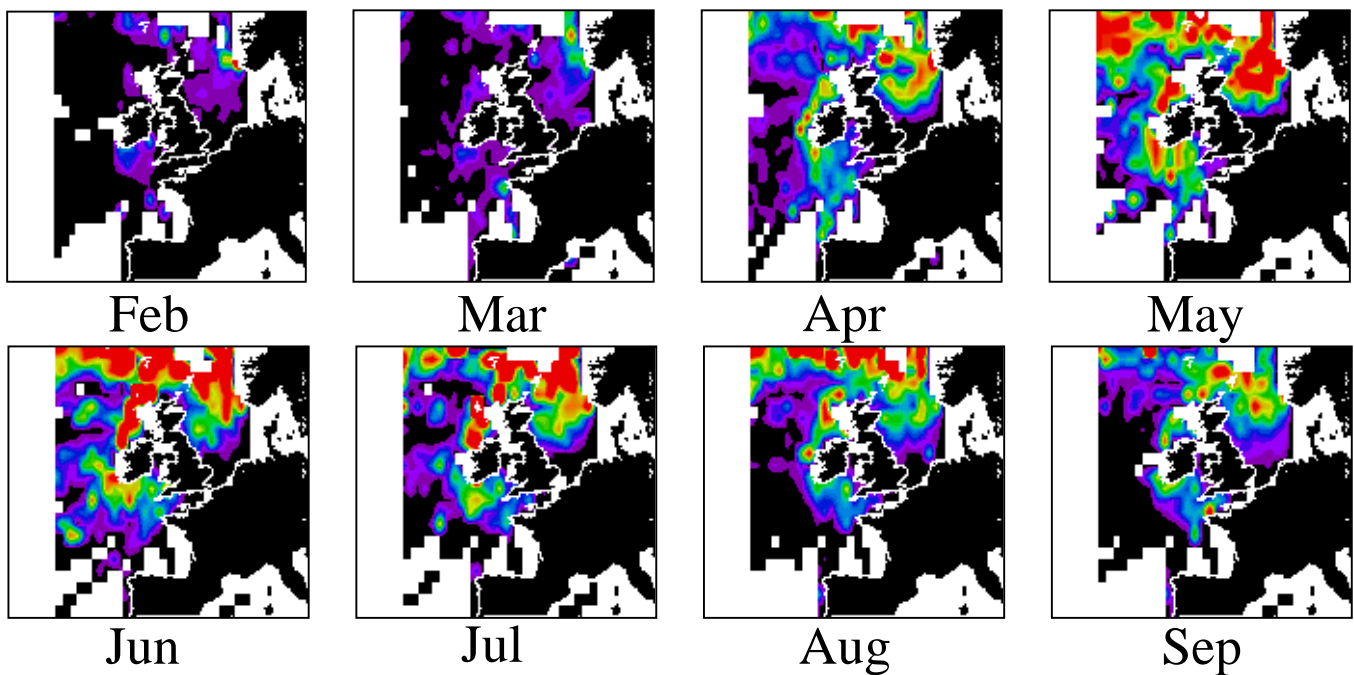


Figure 4: Distribution of Calanus copepods measured by the CPR by month; values are representative of the long term mean. Units are numbers per 3m^3 . Areas masked out in white are where data is unavailable or where the regions were not sampled by the CPR.

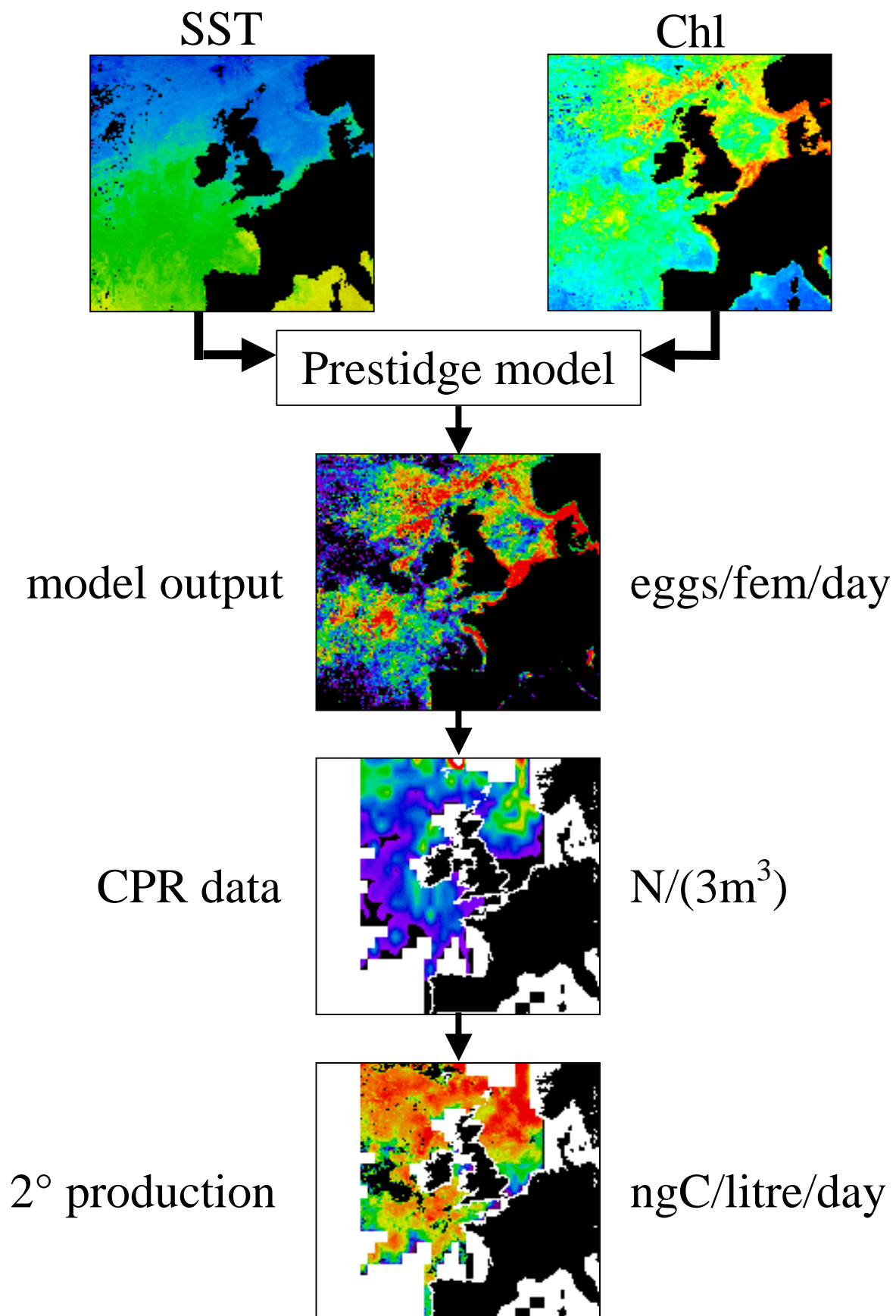
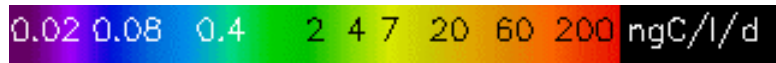
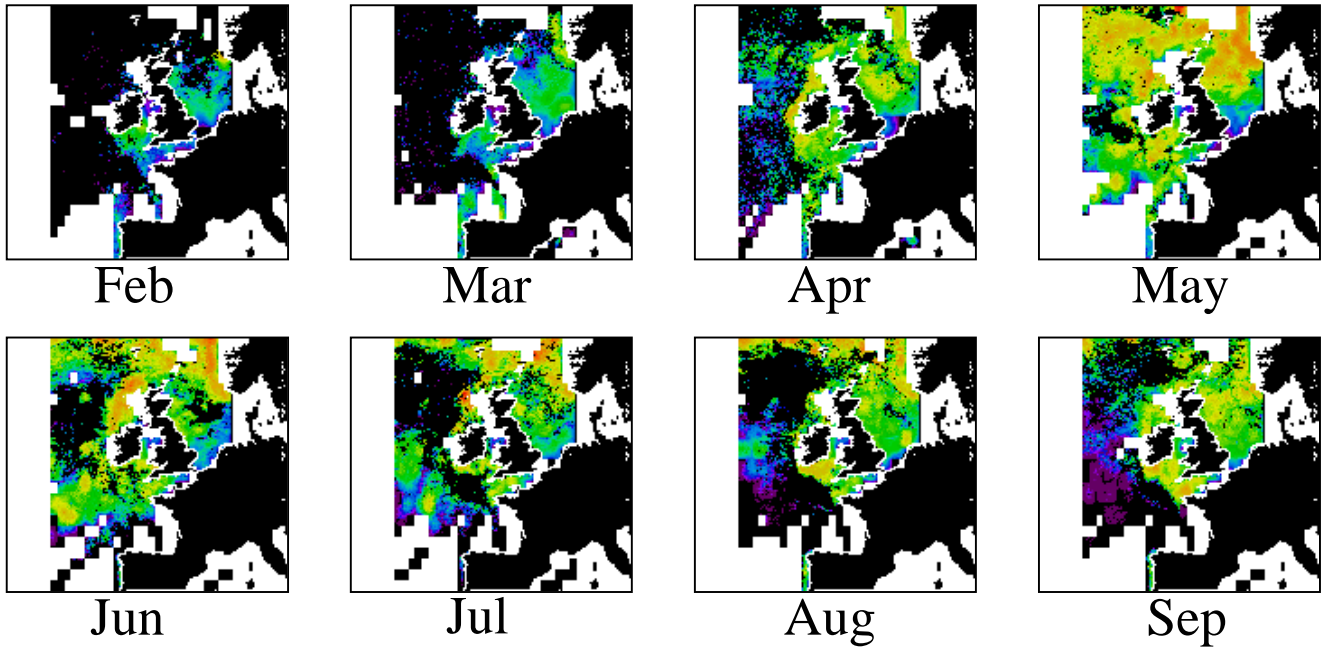


Figure 5: Schematic diagram showing procedure to determine secondary (2°) production using a combination of satellite derived parameters modelling and CPR data



Calanus hel + fin



Acartia clausii

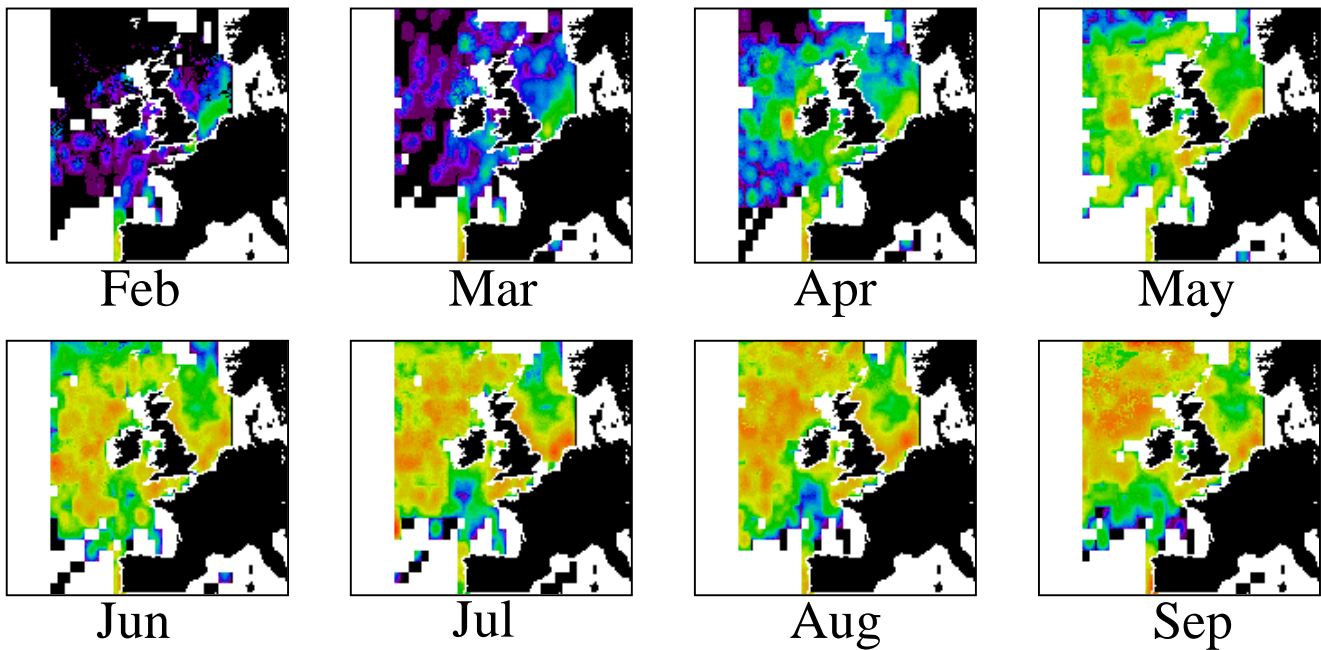


Figure 6: Secondary production of Calanus (top) and Acartia for months of 1998. The same scale applies to both species.