Interannual variability in the relationship between *in situ* primary productivity and chitobiase-based crustacean productivity in a temperate fjord

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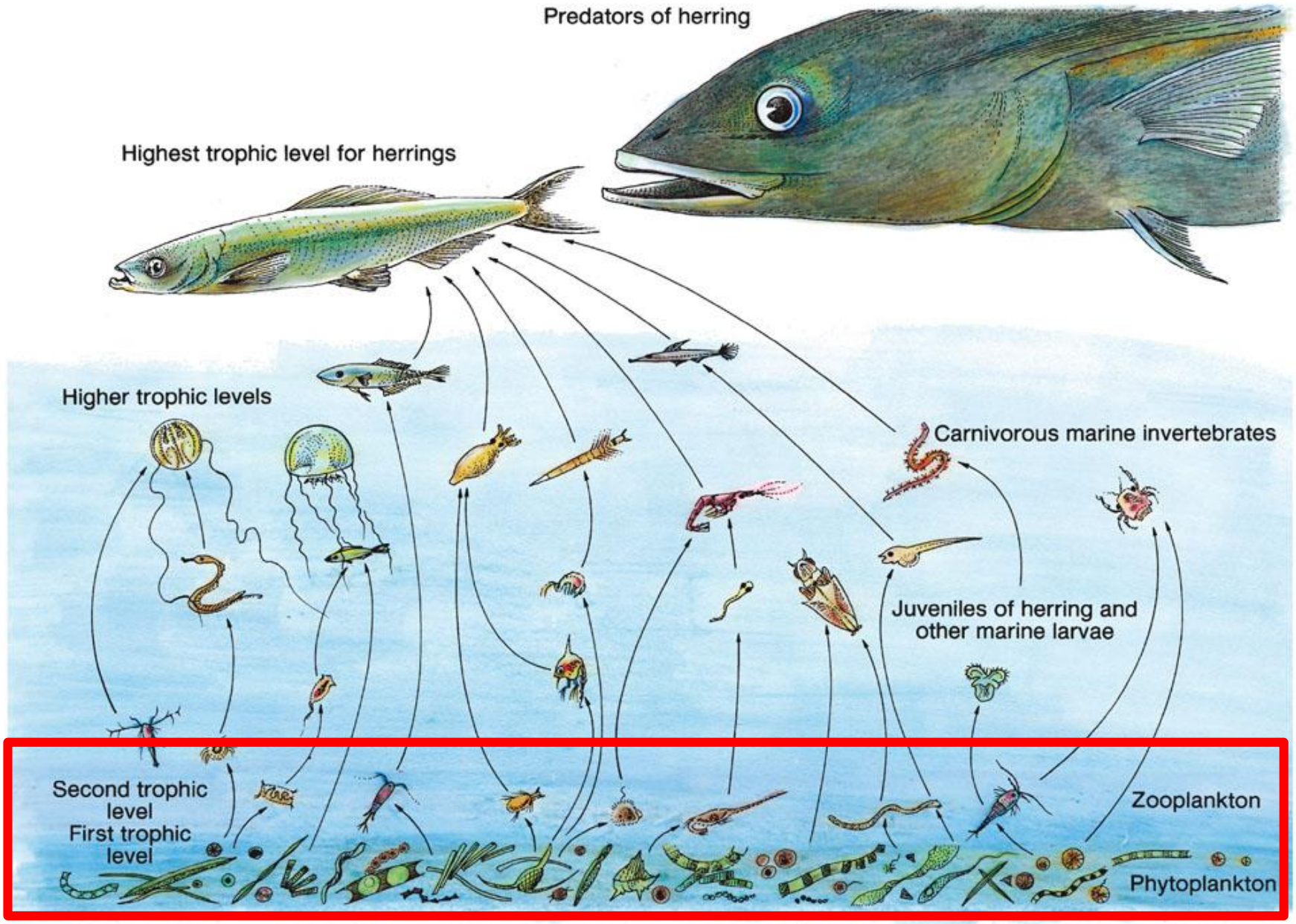
Importance of Lower Trophic Levels



(from Sverdrup *in* Duxbury & Duxbury 2005)

Productivity Estimates

How do we quantify the amount of energy available to higher trophic levels?

Primary Productivity

= Rate at which biomass is produced by photosynthesis

Routinely measured using direct (e.g. ^{13}C) or remote (satellite images) methods

Secondary Productivity

= Rate of increase in biomass of herbivores in a system

Less common:

- time consuming
- involve lengthy incubations
- single or a few species only

Estimating Secondary Productivity

- Traditional methods
  - Incubations/cohort analyses
  - Egg production method
- Global predictive models
- Instantaneous methods
  - Radiochemical
  - Nucleic acid (RNA content)
  - Enzymatic (aminoacyl-tRNA synthetase, chitobiase)

Zooplankton Biomass

- Use bulk zooplankton biomass to estimate production
- Not everything in a zooplankton sample represents food available to larval fish
- Bias depending on the size of the mesh used

Community-level Crustacean Productivity

Chitobiase Method:

- Based on the crustacean moulting enzyme, chitobiase

- Direct estimates of crustacean productivity are obtained by measuring the rate of chitobiase decay

Main advantage: can be estimated directly and rapidly at sea

(Photo by Rebecca Jones)

Chitobiase Method

- Water samples collected from specific depths
- Incubate sub-samples over 24 hours
- Run enzyme assays & measure the fluorescence
- Calculate native chitobiase (CBA_{nat}), stage durations, Daily P:B, and production rates

A Few Key Assumptions…

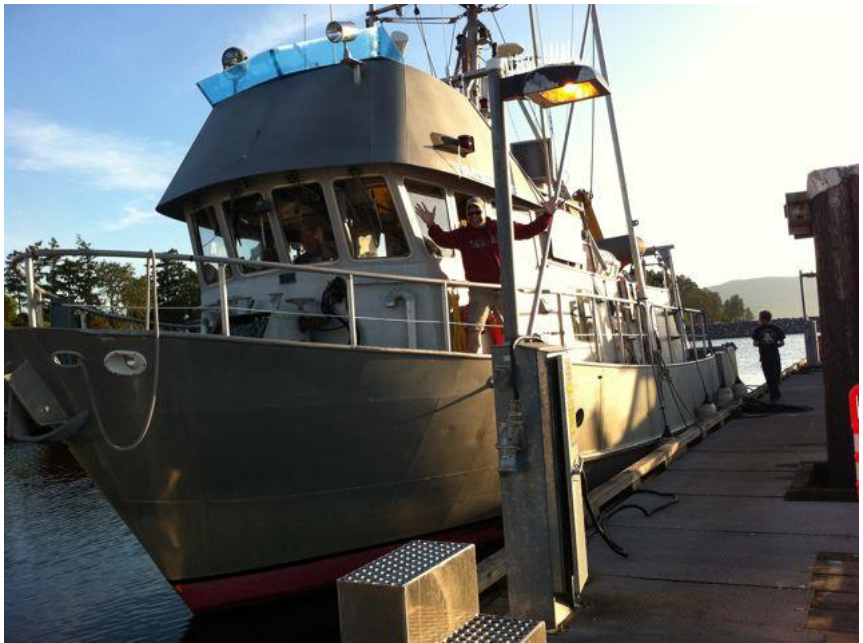
- Changes in primary productivity result in corresponding changes in secondary (crustacean) productivity

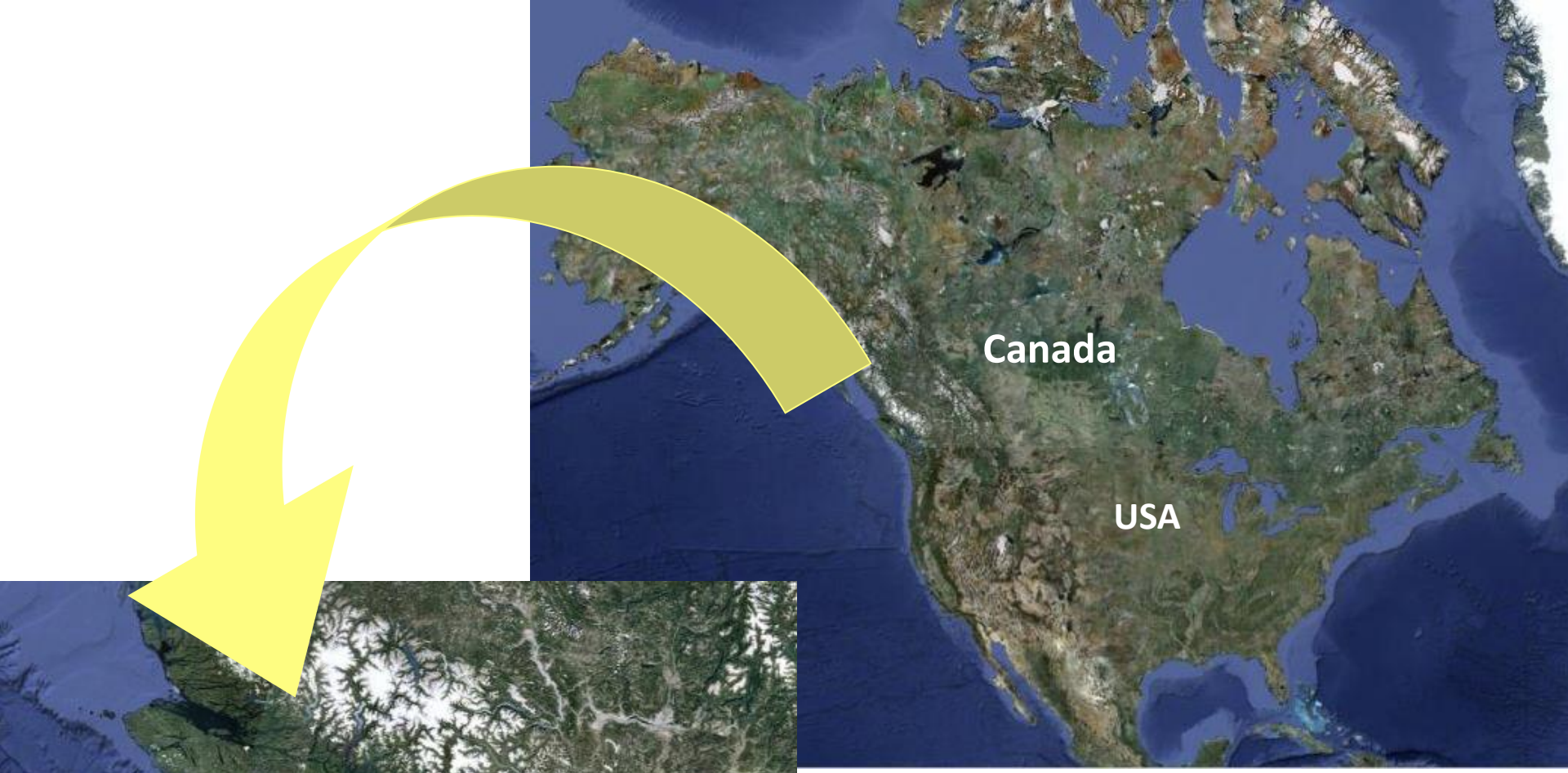
- Trophic transfer efficiency (TTE) between trophic levels is ~10%

Field studies simultaneously measuring primary and secondary productivity rates are lacking

Objective → determine how temporal variations in primary productivity influence crustacean productivity and TTE

First study to routinely couple *in situ* estimates of primary productivity and crustacean productivity




Canada
USA
Vancouver
Island

Saanich Inlet, BC, Canada

- Highly productive 24 km long fjord
- Shallow (~75 m) sill located at the mouth
- Dominant freshwater sources are outside of the inlet
- Strongly influenced by the tidal cycle
- Sampled from March to August 2010 and 2011

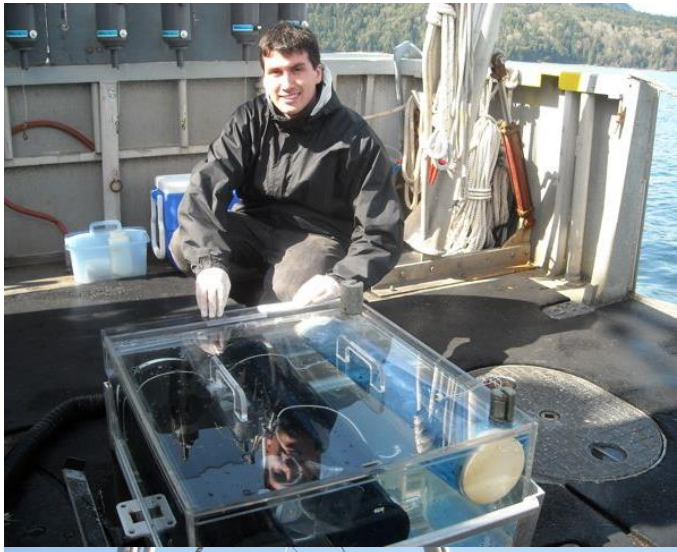
Methods

Phytoplankton (Varela lab)

- Nutrients
- Total and size-fractionated chl *a*
- Biogenic silica
- Phytoplankton community composition
- Primary productivity (^{13}C method)

Zooplankton (Dower lab)

- Vertical zooplankton tows
- Collected copepods for fatty acid analyses
- Crustacean productivity (chitobiase method)

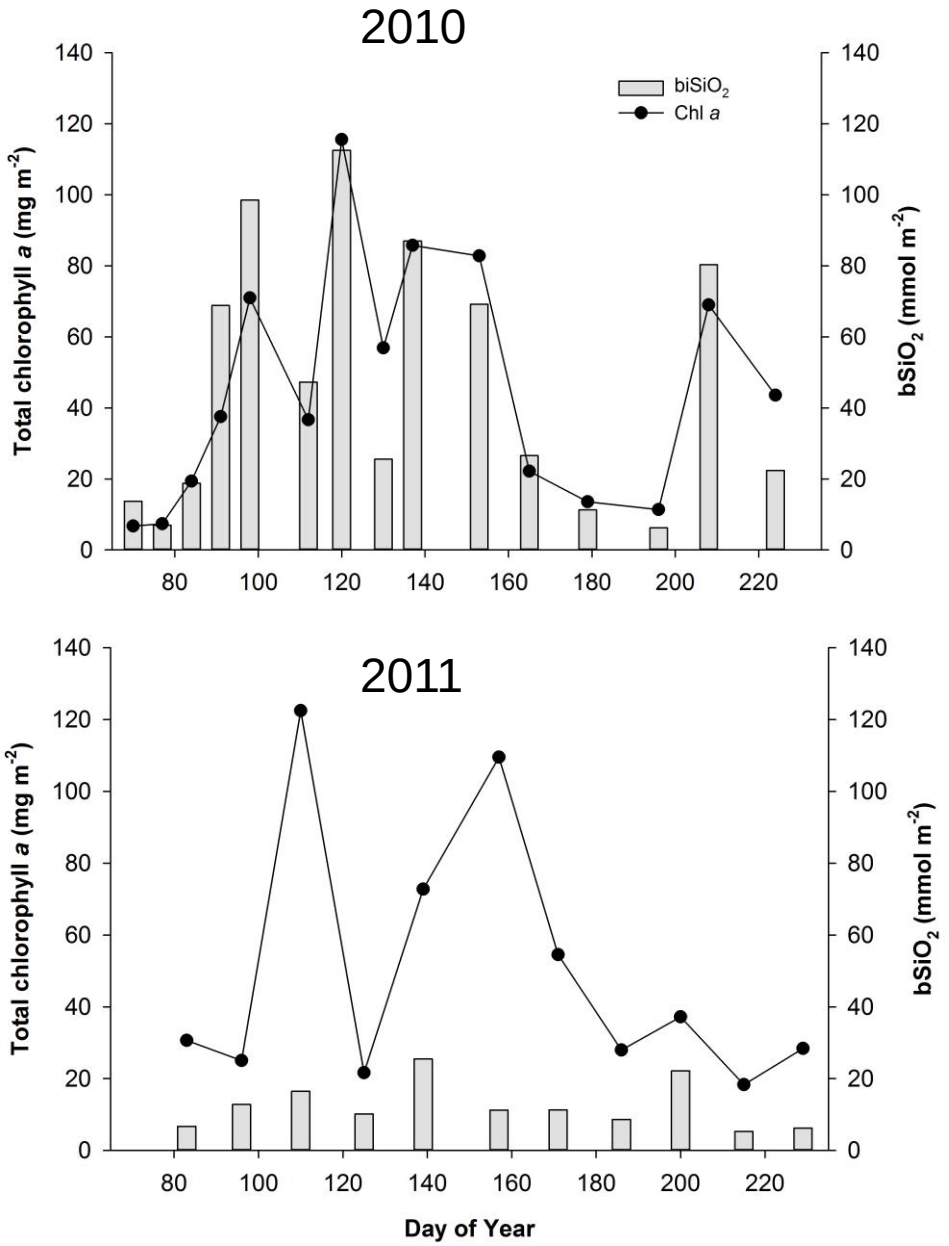


Spring water column properties

	2010 (El Niño)	2011 (La Niña)
Water temp	slightly higher	slightly lower
Salinity	slightly higher	slightly lower
$\Delta \sigma_t$ (kg m^{-3})	less stratified	more stratified
Nutrients	↑ nitrate and silicate	↓ nitrate and silicate

Spring bloom occurred ~2 weeks earlier in 2010

Phytoplankton

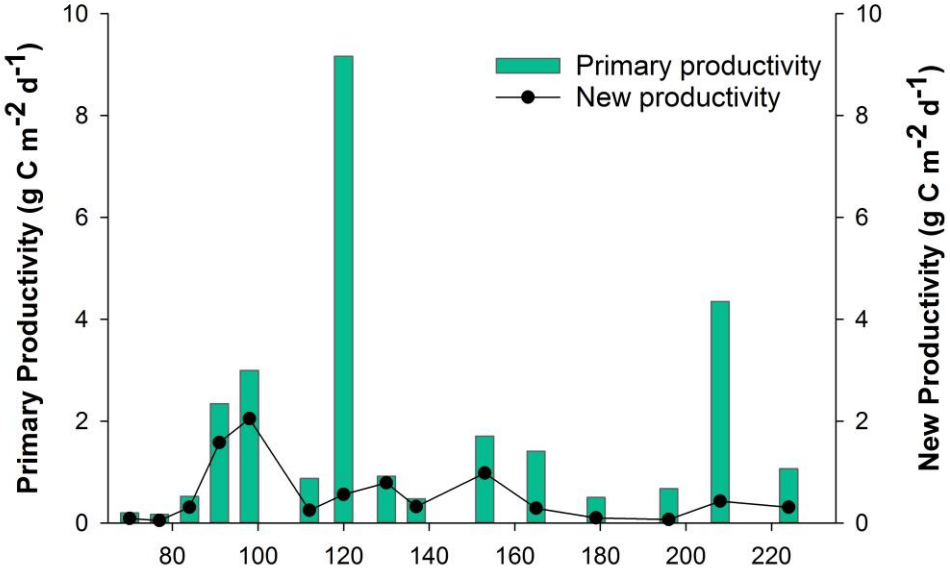


- > 20 µm phytoplankton are the dominant size class in Saanich Inlet
- Initial peak of Chl *a* was a few weeks earlier in 2010
- Range of Chl *a* values was similar for both years
- Higher nutrient concentrations in 2010 led to higher $bSiO_2$ = more diatoms

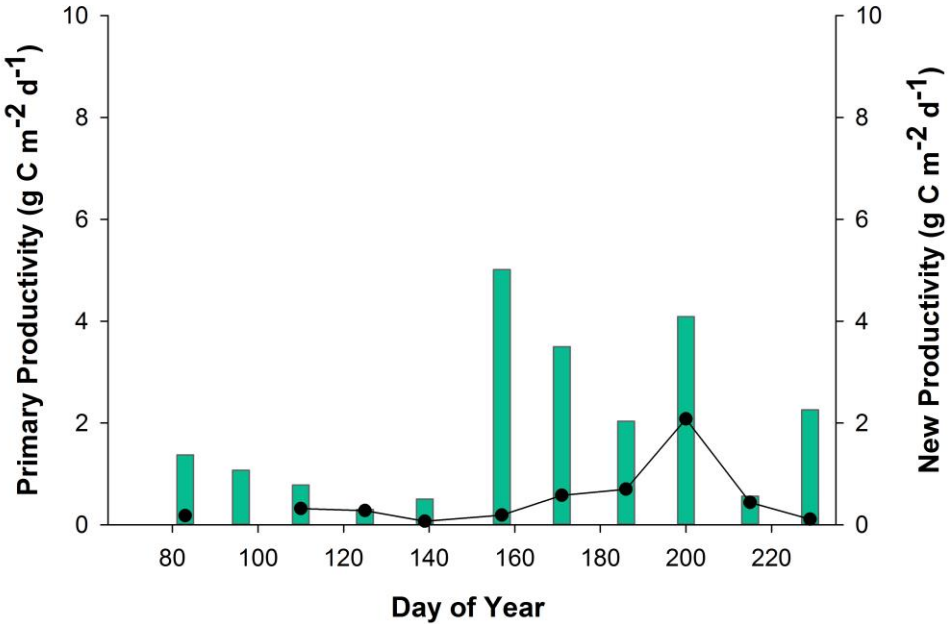
(Suchy et al. 2016, MEPS)

Primary Productivity

2010



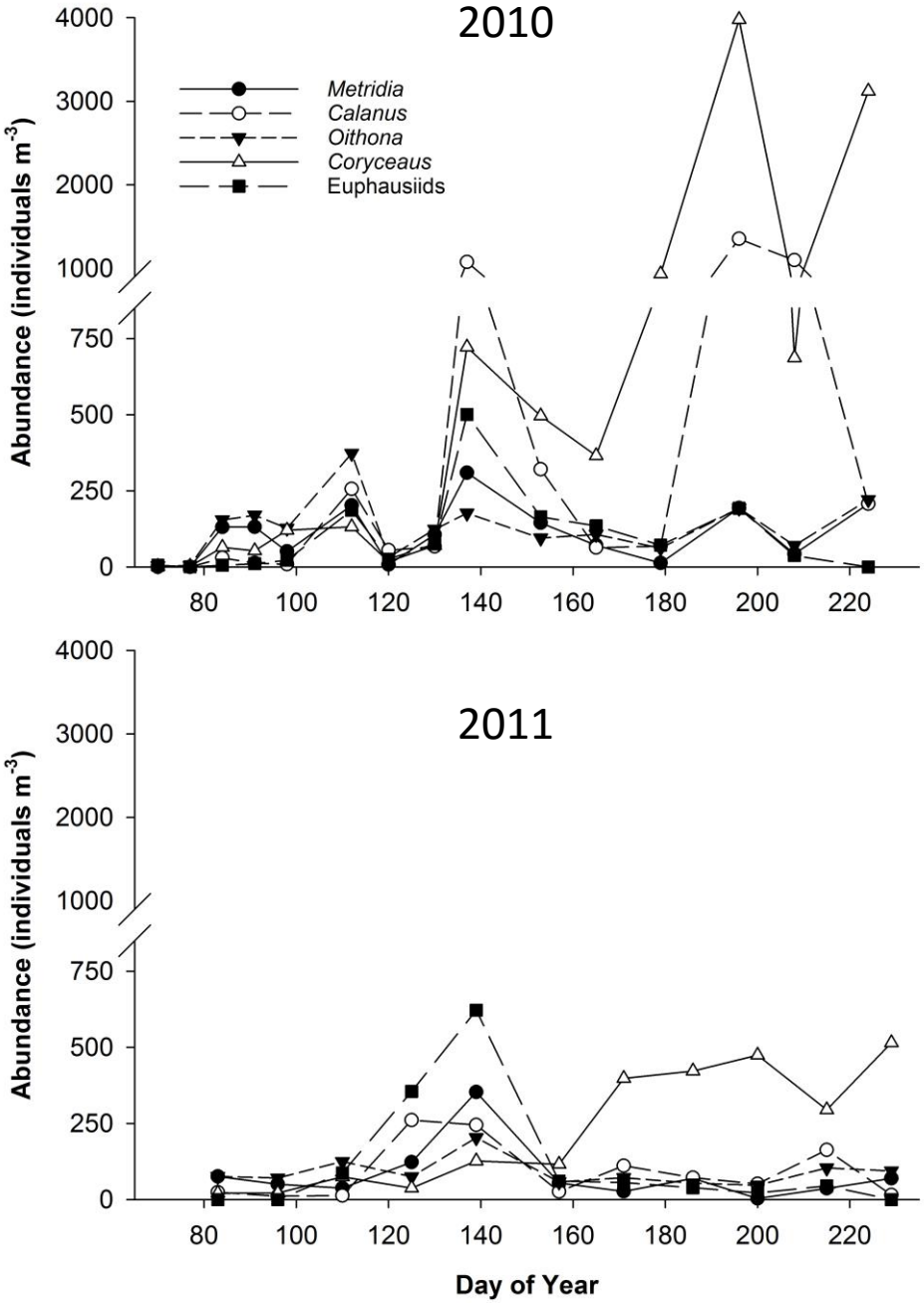
2011

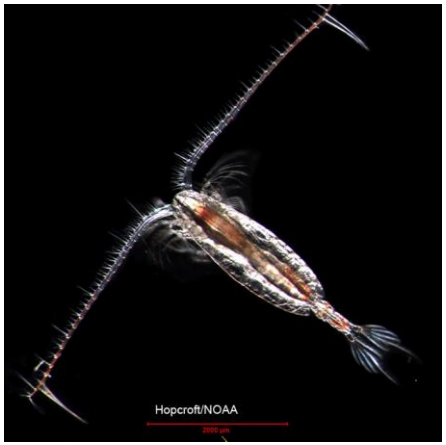


- Higher overall in spring 2010 than in 2011
- Initial peak in 2011 was delayed until early summer (June)
- Mean primary productivity: ~1.8 g C m^{-2} d^{-1} during both years

(Suchy et al. 2016, MEPS)

Crustacean Abundance

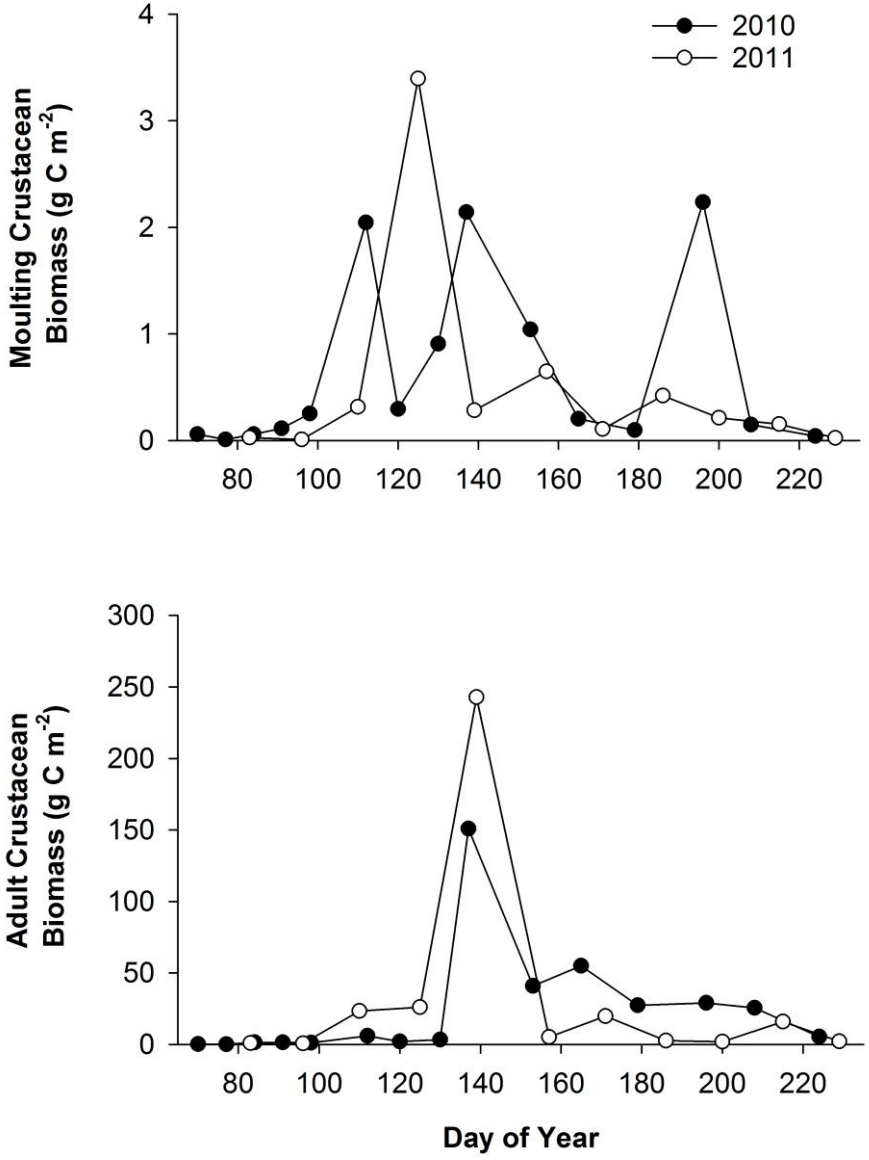




- Abundance was substantially higher in 2010
- Initial peak in crustacean abundance was earlier in 2010
- *Calanus* abundance peaked multiple times in 2010, but only once in 2011

(Suchy et al. 2016, MEPS)

Crustacean Biomass



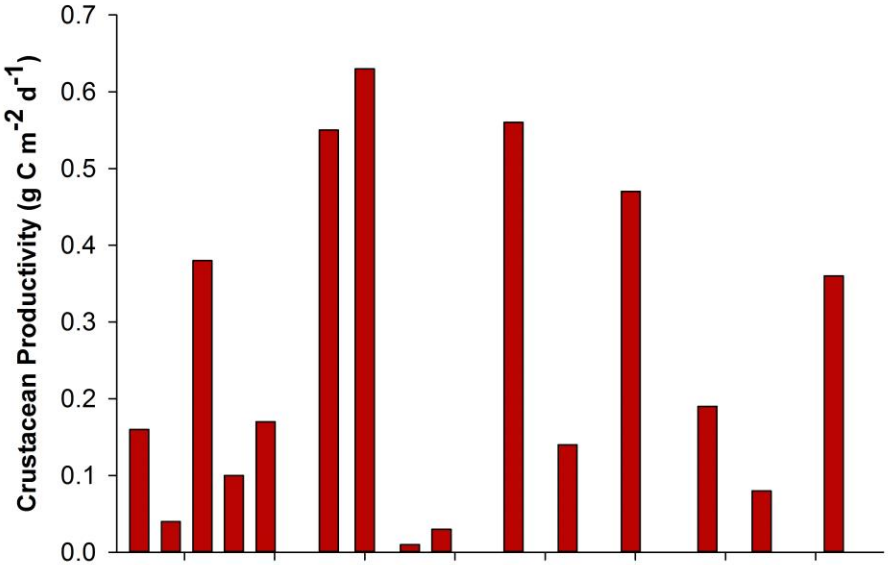
- Biomass of moulting crustaceans (nauplii & copepodites) followed same pattern as abundance

- Adult crustacean biomass peaked at the same time (Day 140) during both years

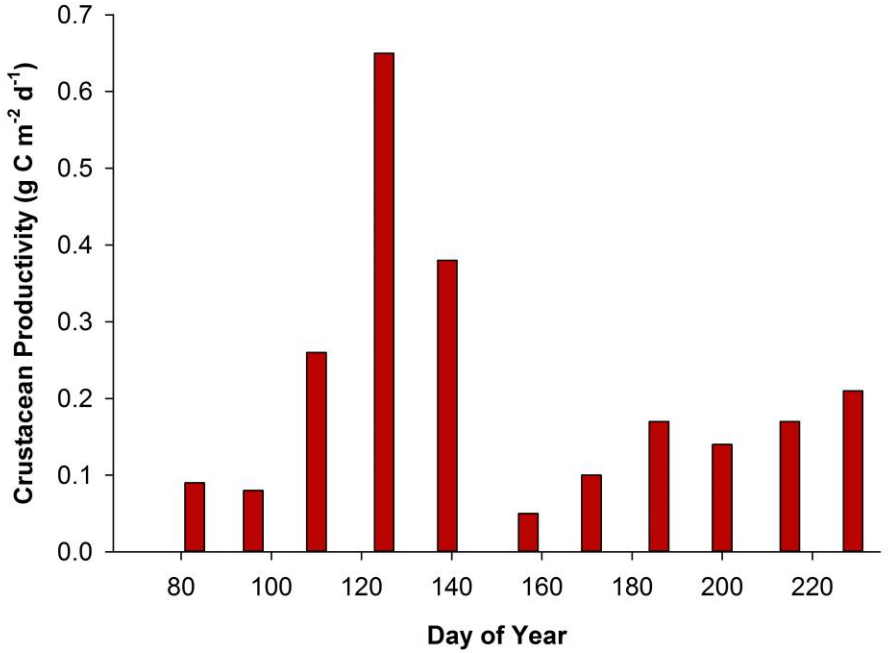
(Suchy et al. 2016, MEPS)

Chitobiase-based Crustacean Productivity

2010



2011



- Crustacean productivity peaked slightly earlier in 2010
- Crustacean productivity was higher in 2010
- Very low productivity in May 2010
- Observed mid-season decrease in productivity occurred in June 2011

(Suchy et al. 2016, MEPS)

Trophic Transfer Efficiency (TTE)

	Day of Year	Time-averaged Primary Productivity (g C m^{-2} d^{-1})	Time-averaged Crustacean Productivity (g C m^{-2} d^{-1})	Trophic Transfer Efficiency (%)	TTE Artefact Samples Removed (%)
2010	74	0.18	0.10	53	-
	81	0.35	0.21	60	-
	88	1.43	0.24	17	17
	95	2.67	0.13	5	5
	105	1.94	0.36	19	19
	116	5.02	0.59	12	12
	125	5.04	0.32	6	6
	134	0.70	0.02	3	3
	145	1.09	0.29	27	27
	159	1.56	0.35	22	22
	172	0.96	0.31	32	32
	188	0.59	0.33	56	-
	202	2.51	0.13	5	5
	216	2.71	0.22	8	8
				Average	**14**
2011	90	2.44	0.17	7	7
	103	1.85	0.34	19	19
	118	1.08	0.91	84	-
	132	0.81	1.03	128	-
	148	5.52	0.43	8	8
	164	8.51	0.15	2	2
	179	5.53	0.28	5	5
	193	6.12	0.31	5	5
	208	4.65	0.31	7	7
	222	2.82	0.38	13	13
				Average	**8**

What does TTE tell us?

- High values of TTE = more energy for higher trophic levels

•Our average values of TTE are within 2-24% (Pauly & Christensen 1995)

•TTE of 10-20% is useful on an annual basis, but we observed substantial seasonal variations from early spring to summer

2010 ranged between 3-32%

2011 ranged between 2-19%

•Extrapolate results to higher trophic levels

– Determine impact of this variability at critical times of the year (e.g. spring bloom)

Summary

- First study to routinely couple *in situ* community-level productivity estimates for phytoplankton and crustacean zooplankton

- Earlier peak in primary productivity in 2010 resulted in more efficient energy transfer from phytoplankton to zooplankton compared to 2011

- Field-derived crustacean productivity estimates are necessary given that low productivity can occur even when zooplankton biomass is high

Comparison with other methods

Region	Method	Productivity Range	Study
Saanich Inlet, Canada	Chitobiase	0.05-15.61 mg C m^{-3} d^{-1} or 0.01-0.65 g C m^{-2} d^{-1}	Present Study
Skagerrak, between Norway and Denmark	Artificial Cohort	3.0-8.0 mg C m^{-3} d^{-1}	Peterson et al. 1991
Coastal region, Denmark	Egg production	0.01-0.16 g C m^{-2} d^{-1}	Kiørboe & Nielsen 1994
Sagami Bay, Japan	Hirst & Lampitt (1998) model	0.09-7.77 mg C m^{-3} d^{-1}	Ara & Hiromi 2007

Limitations of the Chitobiase Method

- Chitobiase released from dead/decaying crustceans may lead to overestimates of productivity
- Exuviotrophic ciliates consuming exuvia fluid after crustacean moulting may result in slight underestimations
- Chitobiase method does not consider the contribution of adult production (i.e. egg production)

Direct Applications

Routine, field-derived productivity estimates are necessary:

1. For accurate calculations of trophic transfer efficiency (TTE)
   - How much phytoplankton is actually consumed by grazers and converted into energy for higher trophic levels?
   - How do seasonal variations in TTE impact higher trophic levels (match/mistmatch)

2. As a model parameter (in addition to biomass) for a more accurate approach to ecosystem-based fisheries management

3. To obtain high spatial and temporal resolution in order to accurately estimate the amount of energy available to fish and other consumers

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