Putting temperature and oxygen thresholds of marine animals in context of environmental change in coastal seas: A regional perspective for the Scotian Shelf and Gulf of St. Lawrence

Catherine E. Brennan, Hannah Blanchard, and Katja Fennel

Department of Oceanography, Dalhousie University, Halifax, NS, Canada

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ABSTRACT We surveyed the literature in order to compile reported oxygen, temperature, salinity and depth preferences and thresholds of important marine species found in the Gulf of St. Lawrence and the Scotian Shelf regions of the northwest North Atlantic. We determined species importance based on the existence of a commercial fishery, a threatened or at risk status, or by meeting the following criteria: bycatch, baitfish, invasive, vagrant, important for ecosystem energy transfer, and predators and prey of the above species. Using the dataset compiled for the 53 regional fishes and macroinvertebrates, we rank species (including for different lifestages) by their maximum thermal limit, as well as by the lowest oxygen concentration tolerated before negative impacts (e.g. physiological stress), 50% mortality or 100% mortality are experienced. Additionally, we compare these thresholds to observed marine deoxygenation trends at multiple sites, and observed surface warming trends. This results in an assessment of which regional species are most vulnerable to future warming and oxygen depletion, and a first-order estimate of the consequences of thermal and oxygen stress on a highly productive marine shelf. If regional multi-decadal oxygen and temperature trends continue through the 21st century, many species will lose favorable oxygen conditions, experience oxygen-stress, or disappear due to insufficient oxygen. Future warming can additionally displace vulnerable species, though we note that large natural variability in environmental conditions may amplify or dampen the effects of anthropogenic surface warming trends. This dataset may be combined with regional ocean model predictions to map future species distributions.

i. Background

Despite a robust understanding of global ocean changes (heat and oxygen content, vertical stratification, pH, and sea level) due to anthropogenic greenhouse gas emissions (Rhein et al., 2013), **coastal (continental shelves, < 200 m) climate change impacts remain challenging to observe, understand, and predict**.

By year 2100 the **northwestern North Atlantic is predicted to be strongly affected by multiple ecosystem stressors, including warming, acidification, oxygen depletion and decreased net primary production** (Bopp et al., 2013), based on a multi-model analysis under business-as-usual emissions.

How marine species will respond to **changing physical and biochemical environmental conditions depends on the combined influences affecting a given region**: a regional perspective is required.

The northwest North Atlantic is an especially variable region: physical and bio-**chemical changes need to be considered in the context of regional variability.**

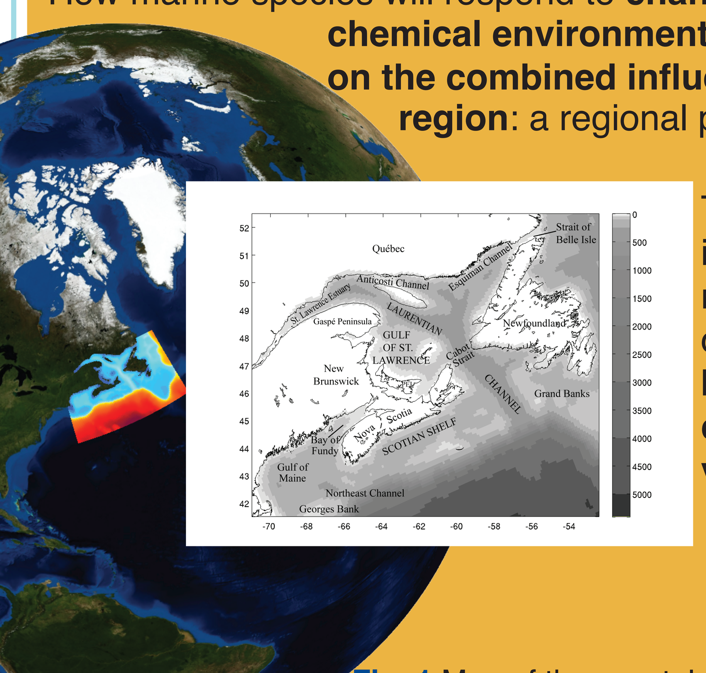


Fig. 1 Map of the coastal northwest North Atlantic between Georges Bank and Newfoundland. Bathymetry (depth in m) is indicated by shading.

The northwest North Atlantic sustains a large fishing economy, historically supporting commercial groundfish, pelagic fish, and shellfish fisheries (O'Boyle, 2012). **Marine species face both environmental pressures from climate change and high fishing pressure.**

Marine species have a unique set of environmental preferences and requirements. While temperature and salinity tolerances have been widely studied, experiments involving oxygen and pH are relatively rare (e.g. Ekau et al. (2010) reviewed oxygen thresholds and the associated impacts on the physiology, reproduction, growth, and mobility for 65 global ocean pelagic species).

ii. Methods

Literature survey:

- Apply criteria to identify important regional species
- Perform literature search for species and lifestage specific information on temperature, salinity, depth, and oxygen requirements, employing both empirical and descriptive studies.

Definition of terms:

- ***Preferred temperature/oxygen***: temperature(s)/oxygen concentration(s) associated with optimal growth.
- ***Temperature range***: total thermal range a species can tolerate or inhabits (based on experiments or observations, respectively).
- ***Critical oxygen***: oxygen concentration associated with negative impacts (e.g. to growth, physiology, reproduction, mobility).
- ***Median lethal oxygen***: oxygen concentration associated with 50% mortality.
- ***No survival oxygen***: oxygen concentration associated with 100% mortality.

Compare to observed regional oxygen trends:

Location	Depth (m)	Trend*	Years	Central trend* (value, yr)	Trend Eqn.
Scotian Shelf	*150*	*-1.06* µmol/m3	*1961-1999*	*154, 1999*	*[O2]= -1.06(yr) + 2272.92*
Cabot Strait	*250*	*-0.88* µmol/m3	*1960-2002*	*178, 1981*	*[O2]=-0.88(yr) + 1921.18*
Lower St. Lawrence Estuary	*320*	*-0.98* µmol/m3	*1932-2003*	*84, 1968*	*[O2]=-0.98(yr) + 2012.55*

(*Trend data from Gilbert et al., 2010, except Scotian Shelf central trend value is 1999 annual average from DFO, 2013).

Off-shelf water masses (Stendardo and Gruber, 2012):

Newfoundland Basin 100-700 -7.3±3.4 µmol/kg 1960-2009

North American Basin 100-700 +4.4±3.8 µmol/kg

Compare to observed regional warming:

Location	Depth (m)	Trend	Years	Source
Scotian Shelf	*0*	*0.89 ºC*	*1982-2006*	*Belkin (2009)*
Gulf of St. Lawrence & Nfld-Labrador shelves	*0*	*1.04 ºC*	*1982-2006*	*Belkin (2009)*
*Gulf of St. Lawrence**	*0*	*1.4 ºC*	*1985-2011*	*Galbraith et al. (2012)**
Lower St. Lawrence Estuary	*320*	*1.65 ºC*	*1932-2003*	*Gilbert et al. (2005)*
Cabot Strait	*250*	*1.95 ºC*	*1932-2003*	*Gilbert et al. (2005)*

(*Gulf of St. Lawrence air temperature proxy for 1873-2011 observations resulted in calculated trend of 0.9°C per century ±0.3°C: within 50 years GSL SST will be higher than any previous record. IPCC (2007) includes nonlinear responses and predicted 3 °C increase in regional air temperature over next century.)

Consider regional variability:

North Atlantic Oscillation (NAO): During the negative (positive) NAO phase, warmer (colder) winters in the Labrador Sea result in a coherent warming (cooling) and increased (decreased) salinity in the Gulf of St. Lawrence and on the eastern Scotian Shelf. At the same time, an increased (decreased) Labrador Current transports cool and fresh (warm and saline) anomalies into the deep western Scotian Shelf. NAO variability produces differences in bottom T and S up to 2°C and 0.4, respectively (Petrie, 2007).

Atlantic Multidecadal Oscillation (AMO): highly correlated with SST anomalies in the Labrador Sea and east of Newfoundland, with largest SST anomaly (~ 0.3°C) found in the latter region (Sutton and Hodson, 2005). A positive AMO phase began in the late 1990s (supplemental warming on top of anthropogenic warming), and based on typical timescales could be expected to persist another two decades or so before a negative AMO cooling signature is again superimposed on anthropogenic warming.

iii. Results: Temperature

Fig. 2 Temperature (T) ranges and preferred T for identified species.

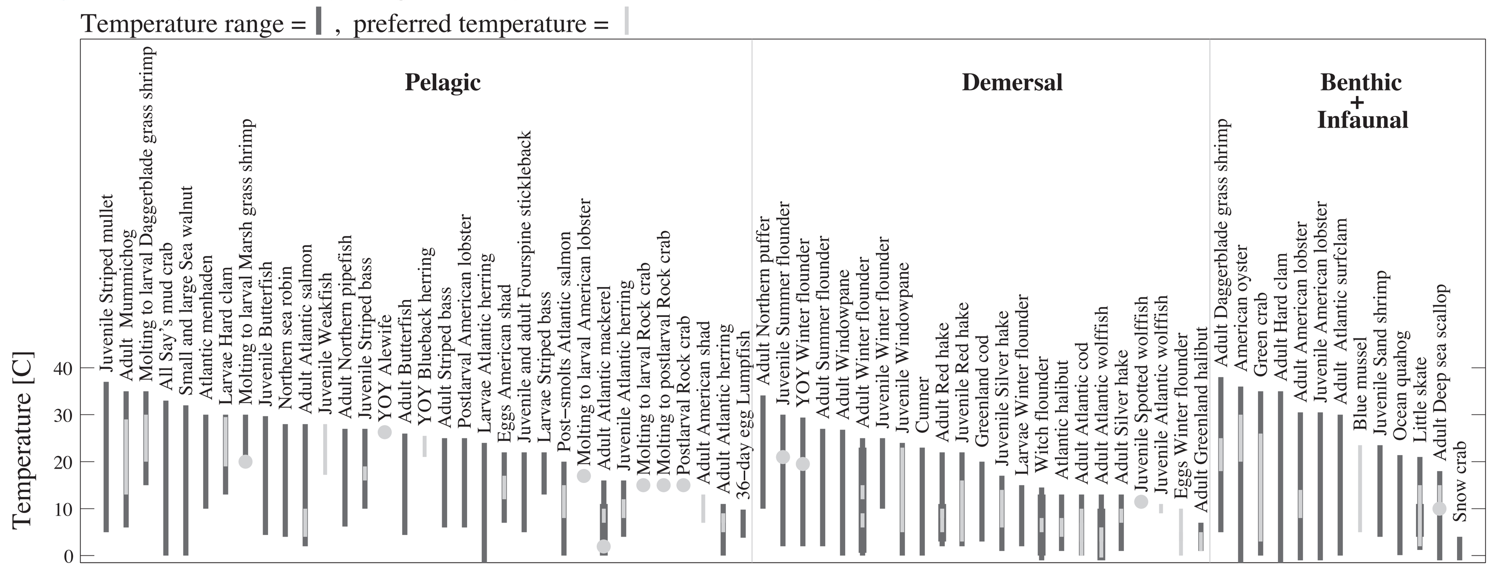
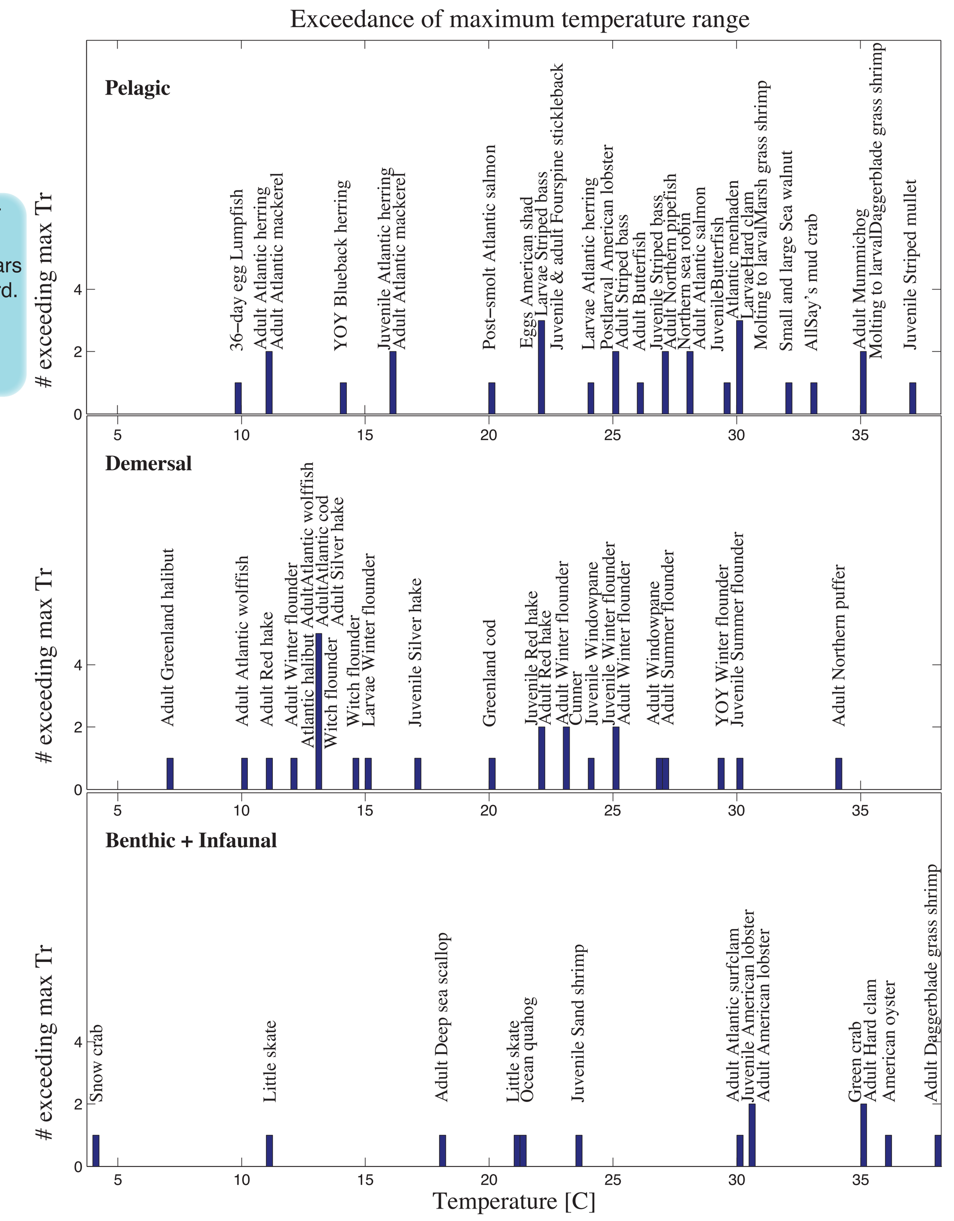
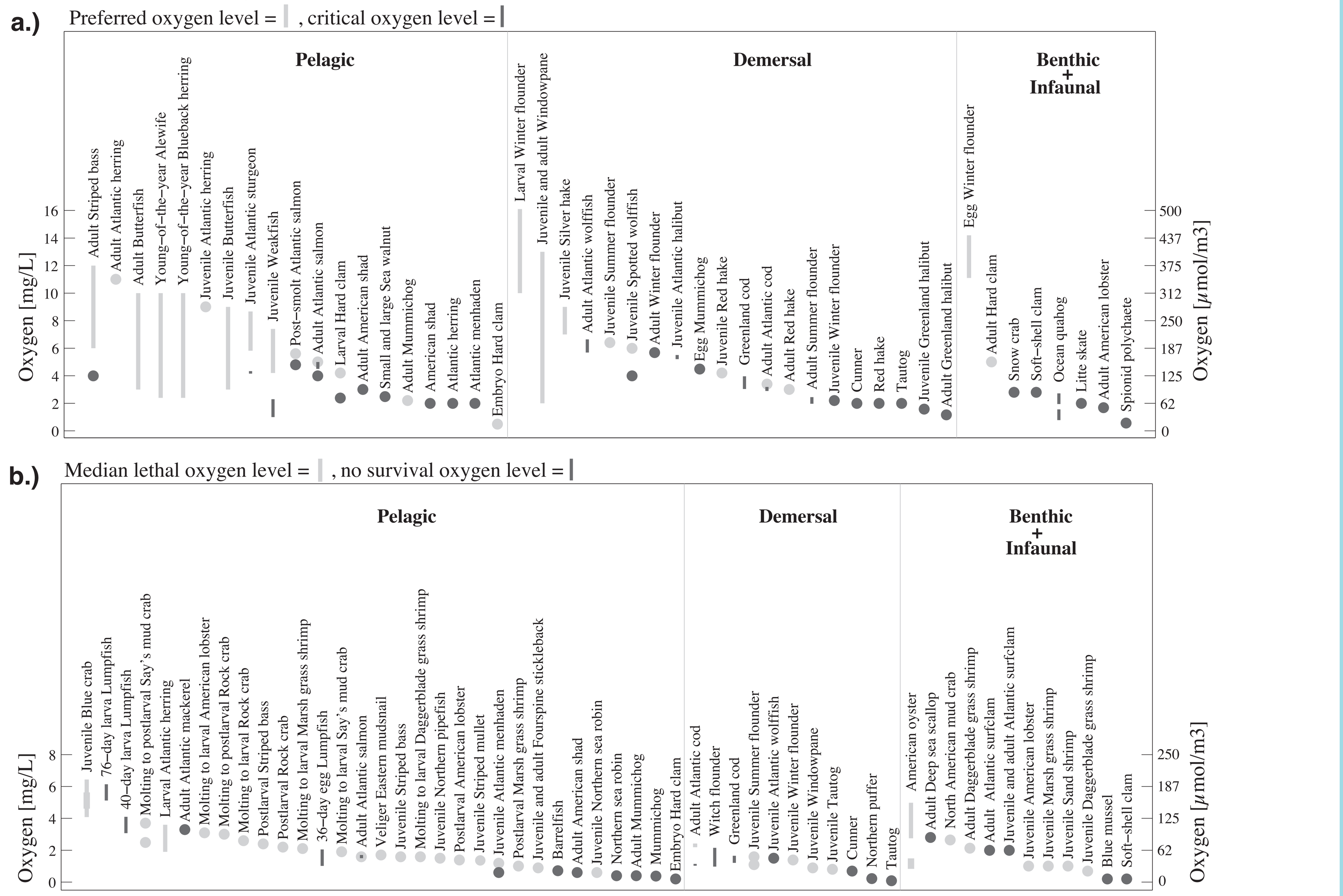


Fig. 3 Histogram of exceedance of upper temperature range for pelagic (top), demersal (center), and benthic and infaunal (bottom) marine species lifestages.



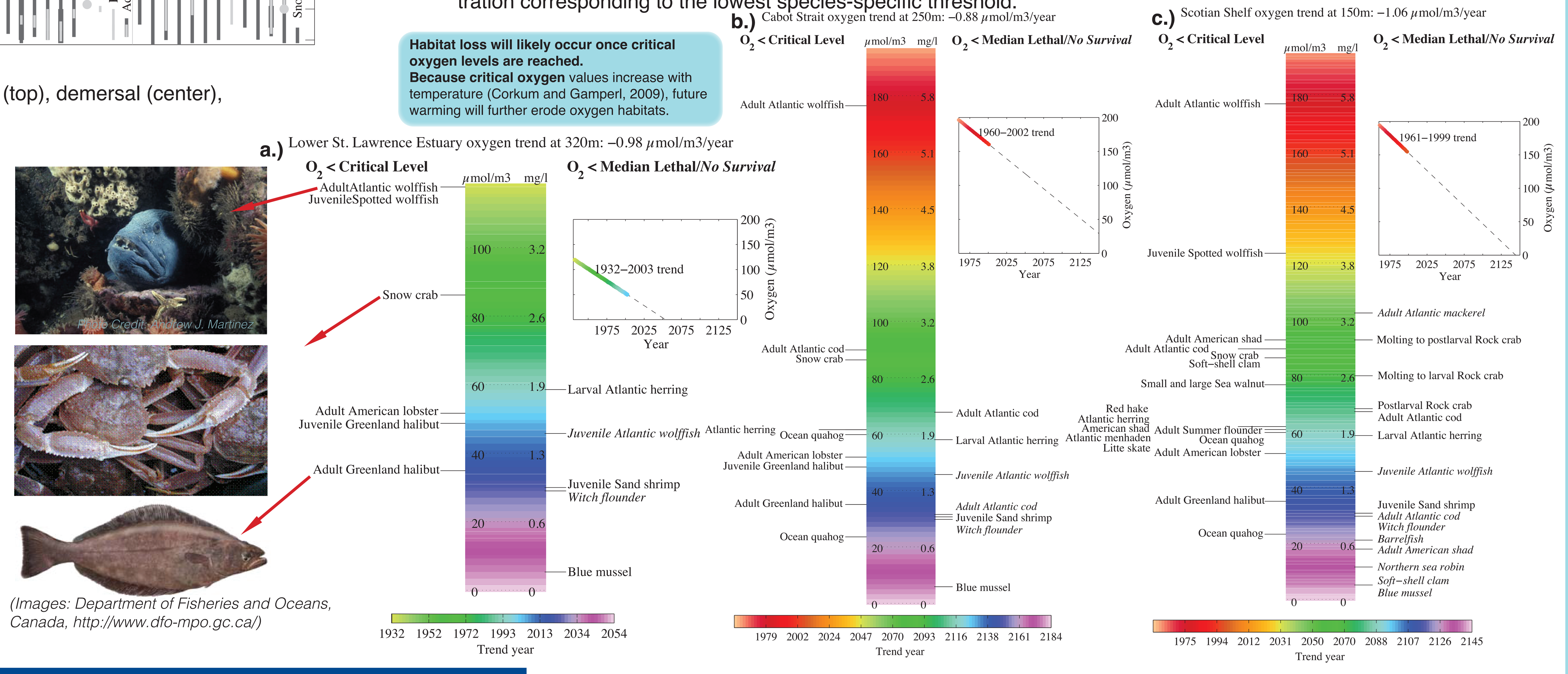
iv. Results: Oxygen

Fig. 4 Oxygen ranges and thresholds for identified species: (a) preferred and critical oxygen, (b) median lethal and no survival oxygen.



Habitat loss will likely occur once critical oxygen levels are reached. Because critical oxygen values increase with temperature (Corkum and Gamperl, 2009), future warming will further erode oxygen habitats.

Fig. 5 Observed temporal oxygen trends (Gilbert et al., 2010) from the Lower St. Lawrence Estuary (a), Cabot Strait (b), and Scotian Shelf (c), linearly projected (see inset plots). The species-level impacts are indicated at the oxygen concentration corresponding to the lowest species-specific threshold.



(Images: Department of Fisheries and Oceans, Canada, http://www.dfo-mpo.gc.ca/)

v. Conclusions

- We investigated temperature and oxygen requirements, reported in literature, of important fish and macroinvertebrate species from the Gulf of St. Lawrence and Scotian Shelf, two economically important marine ecoregions in Eastern Canada.
- Most species in our study region exhibit narrow temperature preferences, and suffer negative impacts (i.e. based on exceeding critical oxygen, median lethal or no survival levels) above the typical hypoxia threshold (2 mg/L) (cf. Vaquer-Sunyer and Duarte (2008)).
- Oxygen declines and temperature increases are occurring in both regions. If regional trends continue, many species will encounter unsuitable temperature or oxygen conditions within the next century.
- Projected regional temperature trends and natural variability are both large, and natural variability will act to alternately amplify and dampen anthropogenic surface warming.
- When and if combined with biogeochemical models, this dataset can aid in the prediction of regional habitat loss and species shifts.

vi. References

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