Effects of UV filters on corals: Current knowledge, data gaps, and challenges in interpretation

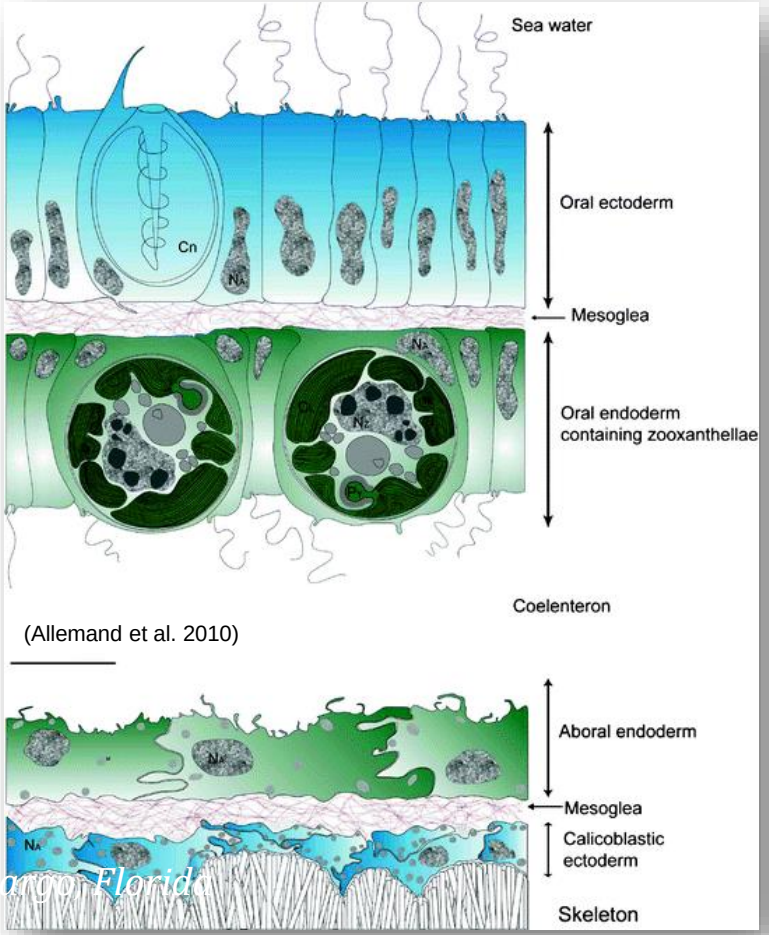
NASEM, Environmental Impacts of Sunscreens, August 5, 2021

D. Abigail Renegar, Ph.D.
Research Scientist

Nova Southeastern University
Halmos College of Arts and Sciences
Dept. of Marine and Environmental Science
8000 North Ocean Drive, Dania Beach, FL 33004

Corals are complex organisms

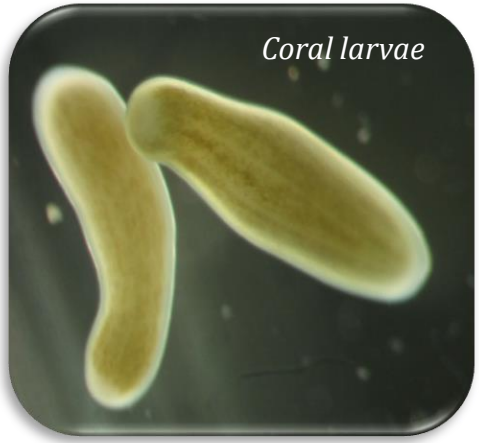
Coral reefs are highly complex environments

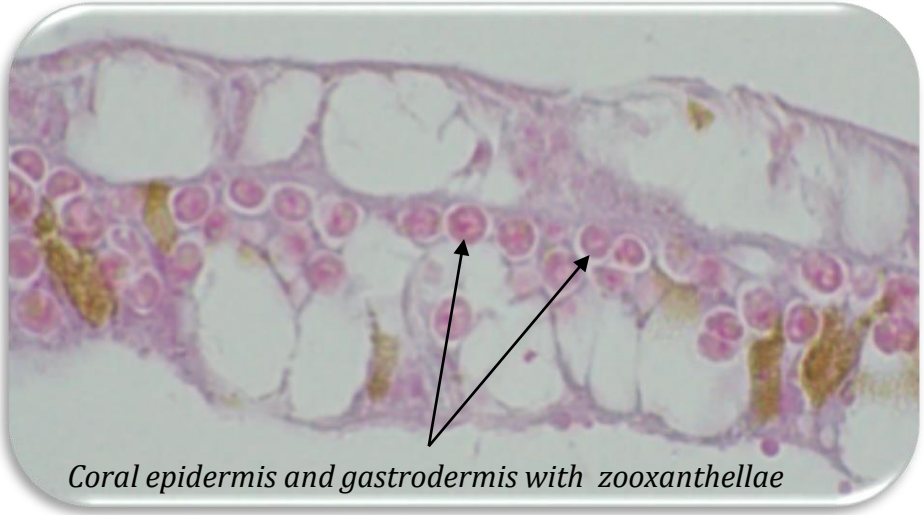


ongo, Florida

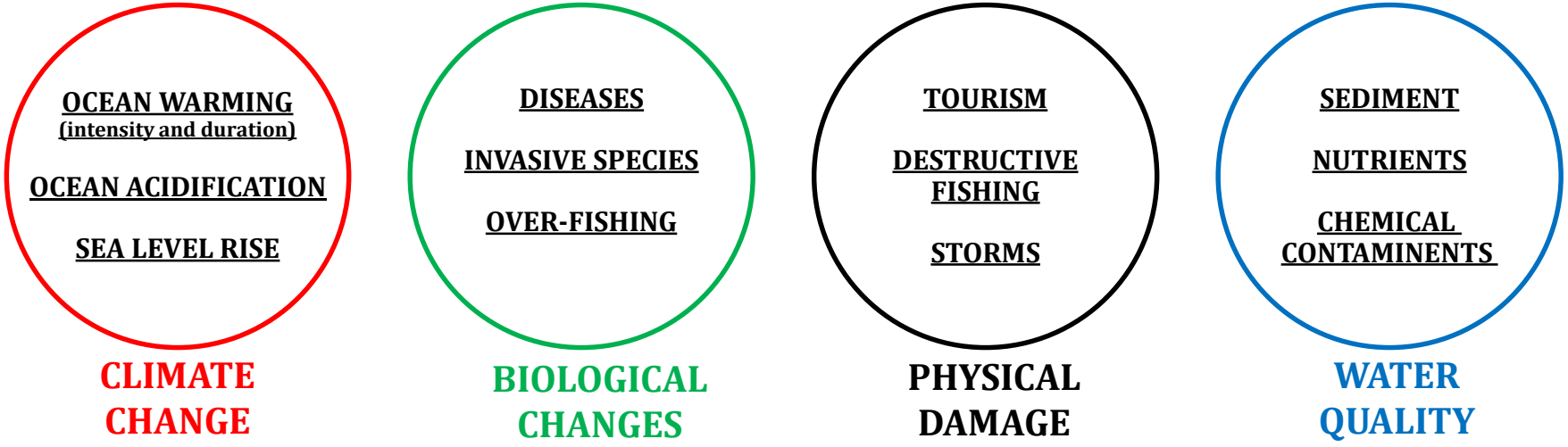
Coral as a test organism

- Temperature, salinity
- Water quality requirements
  - pH, alkalinity, etc.
- Seawater source, filtration
- Light, nutrition
  - Mixotrophic holobiont
- Life stages
  - Variable sensitivity
- **Species-specific variability**





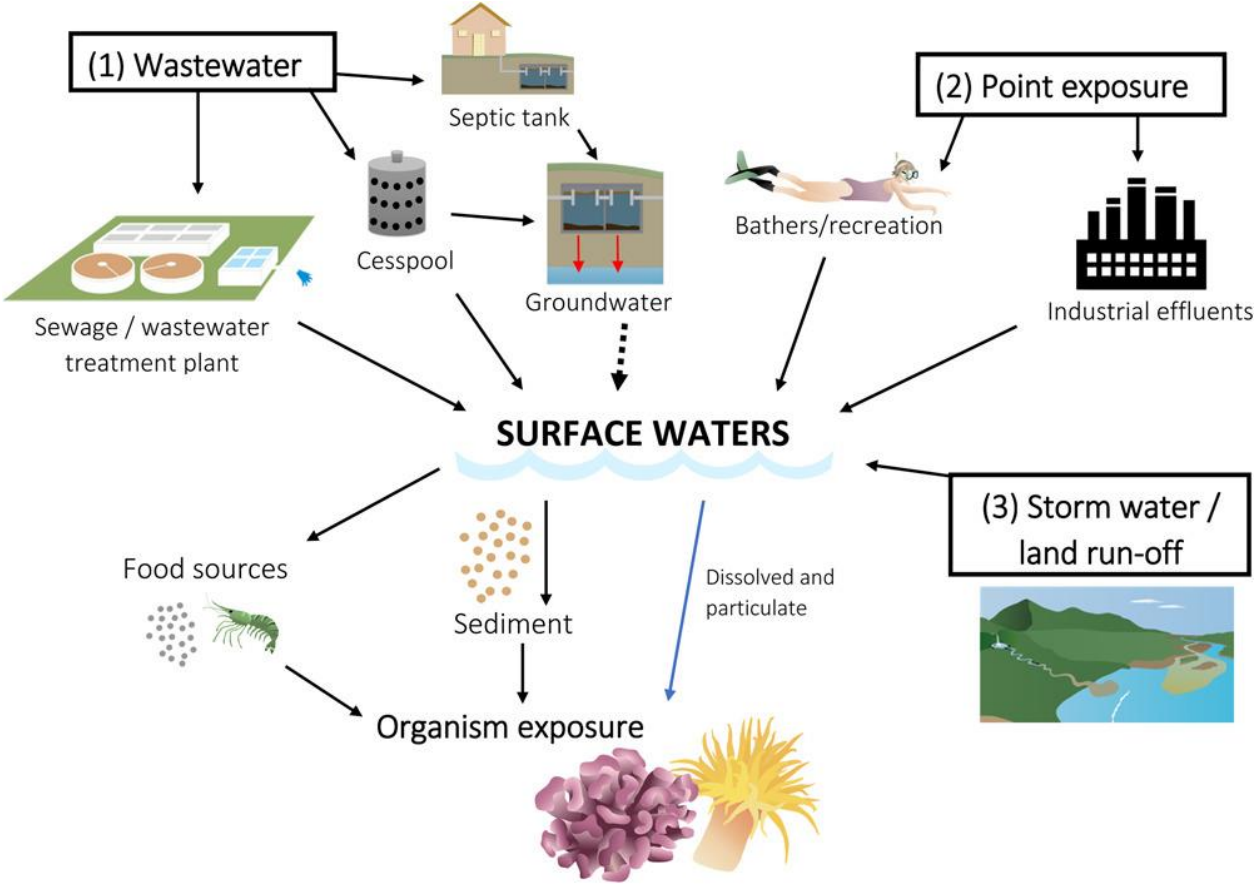
Global and local anthropogenic stressors to coral reefs



- Mitigating global stressors is a national and international priority
- Management of local physical, chemical and biological stressors to increase resilience

- Many different chemical contaminants detected near reefs; nearshore reefs tend to be more vulnerable to land-based sources of pollution

Potential exposure routes for contaminants



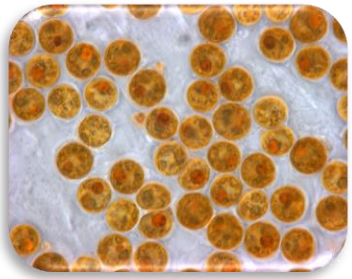
- Point and non-point sources
- Acute and chronic exposures
- Multiple exposure routes (dissolved or particulate, sediment or dietary sources)
- Various life stages in different locations i.e. larvae at surface, corals benthic

Mitchelmore, C.L., Burns, E.E., Conway, A., Heyes, A. and Davies, I.A. (2021), A Critical Review of Organic Ultraviolet Filter Exposure, Hazard, and Risk to Corals. Environ Toxicol Chem, 40: 967-988. https://doi.org/10.1002/etc.4948

Endpoints in coral stressor assays

Acute:

- Mortality/survival
- Tissue changes
- Tissue loss
- Bleaching/symbiont expulsion
- Reduced zooxanthellae density
- Disruption of symbiosis
- Polyp/tentacle retraction
- Polyp swelling & distension
- Excess mucus production
- Decreased tactile response
- Oxidative stress/Antioxidants
- DNA damage
- Gene expression changes
- Microbiome community changes
- Metabolomic changes



Coral host vs algal symbiont or both

Chronic:

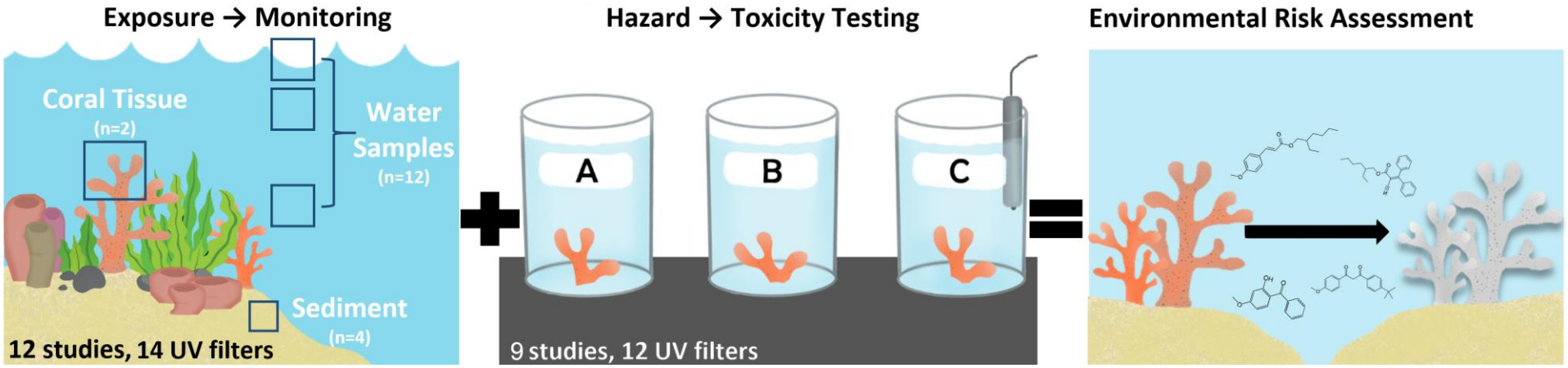
- Reduced growth
- Reduction in coral fecundity
- Inhibition/reduction of fertilization
- Inhibition/reduction larval settlement success
- Deformation & behavioral anomalies in larvae
- Inhibition/changes in larval metamorphosis
- Reduced metabolism
- Reduced calcification

- Pigment (chlorophyll) content
- Photosystem II inhibition, reduced photosynthetic efficiency of endosymbionts (PAM fluorometry)

Other considerations:

- Increased susceptibility to bleaching
- Increased susceptibility to disease
- Increased severity of disease.
- Reduced resilience
- Increased susceptibility to other stressors

Review of UV Filter exposure, hazard and risk to corals

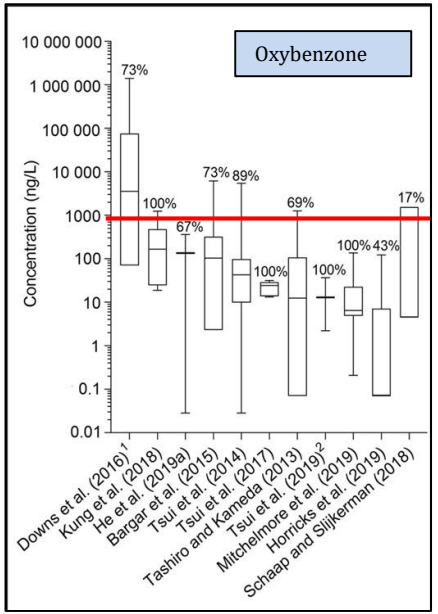


- **Emerging field:** many recent studies, 60% toxicity studies published since 2019 (< 50% of UV filters studied)
- **Exposure and Fate**: 12 studies; up to 14 UV filters measured in seawater near coral reefs
  - Benzophenone-3 is the most commonly measured
  - Majority concentrations in the ng/L (parts per trillion range)
- **Toxicity and Risk Assessments**: 9 toxicity test studies
  - Comparisons challenging given many different testing approaches used
  - Wide range of toxicity endpoints and thresholds, limited data for risk assessments
  - No standard toxicity test protocol for corals

Mitchelmore, C.L., Burns, E.E., Conway, A., Heyes, A. and Davies, I.A. (2021), A Critical Review of Organic Ultraviolet Filter Exposure, Hazard, and Risk to Corals. Environ Toxicol Chem, 40: 967-988. https://doi.org/10.1002/etc.4948

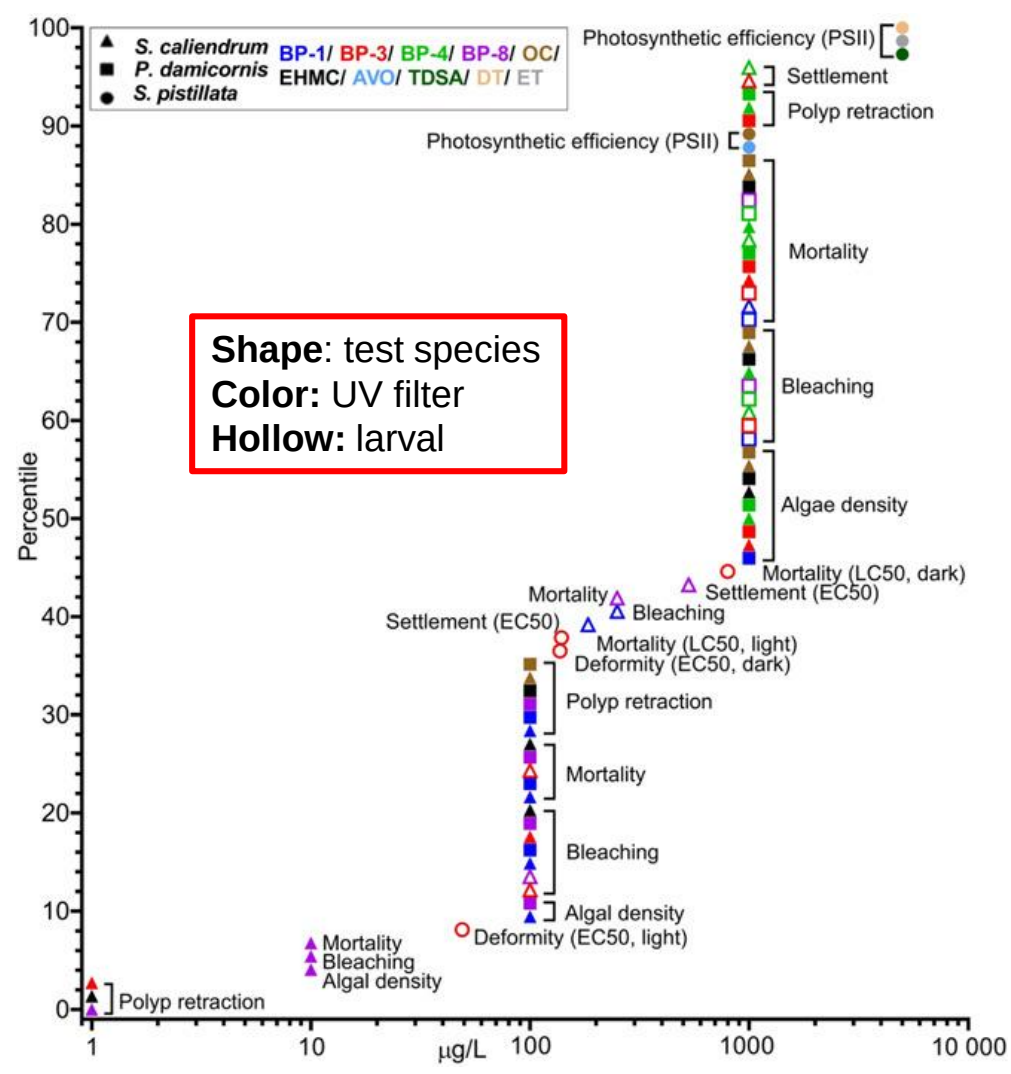
Exposure – near reef water column

% = detection frequency



- Highly variable detection frequency between UV filter in different studies
- High variability among samples.

Mitchelmore et al. (2021)



Cumulative endpoint distribution

Data from 4 acute and chronic studies:

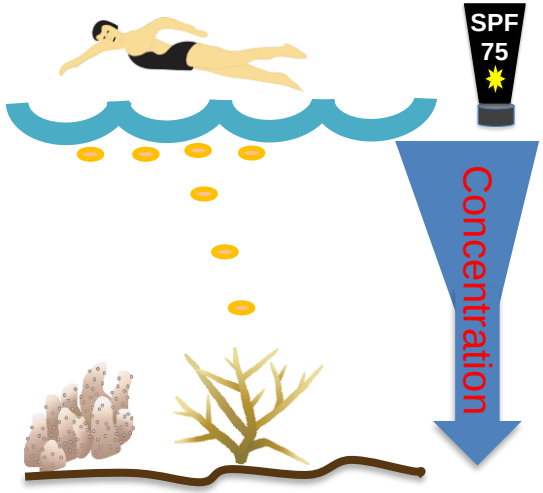
- In many studies, effects not seen at the highest concentrations used
- For many endpoints, threshold used is the conservative HNOEC or NOEC
- Wide variation in endpoints used, polyp retraction most sensitive
- *S. caliendrum* more sensitive than *P. damicornis*

Mitchelmore et al. (2021)

Data Gaps

UV filter sources/inputs

- Very **limited monitoring** data near coral reefs (microlayer, water column, sediment, coral).
- Conduct source identification / apportionment studies
- Isotopic analyses and identification from household and other products, chemical tracers (e.g. sucralose for wastewater tracing)
- Correlations of UV filter levels with recreational activities / other anthropogenic influences.
- **Large variation in analytical methods** (i.e. filtration). What is being measured? Exposure relevance?



Mitchelmore et al.(2021)

Exposure/Fate

- **Spatial variability:** most studies measure UV filters in surface seawater and yet corals are often at deeper depths and larvae are at the surface (i.e. microlayer exposure).
- **Temporal variability:** often single snapshots yet vary with tidal cycle, day, season etc.
- **Fate:** Very little known on the persistence, transport and partitioning in seawater of UV filters.

Toxicity

- Very different experiments performed (time/type).
- No standard test protocol (or species) for corals.
- No **replication** of studies, many with no **analytical verification** of UV filter exposure concentrations.
- Variability with species / life stage.
- Multiple endpoints: which is the most sensitive or representative of coral health?

NUTRIENTS

- Ammonia, nitrite, nitrate, phosphates.
- Higher concentrations near developed coastlines.

METALS

- Aluminum, cadmium, cobalt, copper, gallium, iron, lead, manganganese, mercuroy, nickel, tins, vanadium, zinc, tributyltin (TBT), 2-methoxyethylmercuric chloride (MEMC) (organometallics)
- Highly particle reactive, concentrations may exceed threshold near ports or harbors.

HYDROCARBONS

- Fuel oils, crude oil, gasoline.
- May accumulate in sediments, higher concentrations at water surface.

HERBICIDES

- Diuron, atrazine, 2,4-D, Irgarol 1051, simazine, glyphosate, ametryn, hexazinone, tebuthiuron, ioxynil.
- Ubiquitous in coral reef waters, high water solubility.

INSECTICIDES

- Dichlorodiphenyltrichloroethane (DDT), hexachlorobenzene (HCB), dieldrin, chlordane, organophosphates, carbamates, organotins, pyrethroids. endosulfan, chlorpyrifos, profenofos, carbaryl.
- Ubiquitous in coastal watersheds.

ORGANOCHLORINES

- Biphenyls (PCBs), polychlorinated dibenzodioxins (PCDDs), dibenzofurans (PCDFs).
- Widespread in aquatic environment, persistent.

Observed effects

Metals	Insecticide	Herbicide	Hydrocarbons	Organochlorines	UV Filters
Fertilization success	Fertilization success	Fertilization success			
Settlement	Settlement	Settlement	Settlement		Settlement
Larval survival	Larval survival		Larval survival		
Larval swimming velocity					
Abnormal larval development					Abnormal larval development/deformity
Juvenile survival	Juvenile survival	Juvenile survival			
Respiration					
Bleaching	Bleaching	Bleaching	Bleaching	Bleaching	Bleaching
Chlorophyll Conc.	Chlorophyll Conc.	Chlorophyll Conc.	Chlorophyll Conc.		
Symbiont density	Symbiont density	Symbiont density	Symbiont density		Symbiont density
Tissue/colony mortality	Tissue/colony mortality	Tissue/colony mortality	Tissue/colony mortality	Tissue/colony mortality	Tissue/colony mortality
Growth		Growth	Growth	Growth	Growth
MQY		MQY	MQY	MQY	MQY
EQY	EQY	EQY	EQY		
Production		Production			
	Polyp activity	Polyp activity	Polyp activity		Polyp activity
		Mucus production	Mucus production		

Metals: essential and non-essential, a range of MOA; (Some of same class may impact early life stages more than other (copper vs zinc or cadmium); **Insecticides:** many are acetylcholinesterase inhibitors; **Herbicides:** most are PSII inhibitors, ultimately impact the coral (metabolic status), differential impact in adults vs juveniles; **Hydrocarbons:** lipophilic, narcosis primary MOA (maybe!)

Nalley et al. (2021), van Dam et al. 2011)

- Different contaminants within the same class may have different modes or mechanisms of action
- Many physiological outcomes are observed across classes of contaminants, making attribution of observed effects difficult. Molecular methods may provide some insight.

Multiple stressor studies

- Observed effects from multiple stressors can be **additive** (combined effects =sum of individual), **synergistic** (combined effects > sum of the individual), **antagonistic** (combined effects < sum of individual)
- Interactions may be **different** or even **opposite** depending on the **magnitude** of the exposure.

- Effects of diuron were inversely related to temperature over the range 20 to 30°C, although initially the effects were less at lower temperature (Jones and Kerswell 2003).
- The combination of elevated SST and Cu did not interact to affect coral metabolism (Nystrom et al 2001)
- Effect of the herbicides on photosynthesis of coral symbionts decreased as temperature increased from 26 to 30°C, indicative of an antagonistic interaction (Jones 2003)
- Subadditivity at low temperature-Cu combinations, increasing to additive effects at temperatures < 31°C, becoming strongly synergistic at temperatures between 31°C and 33°C and Cu concentrations up to 30 ug/L (Negri and Hoogenboom 2011).
- Additive effects of elevated SST and herbicide on photosynthetic efficiency of coral symbionts, and effect of either diuron or atrazine in combination with higher SST on chronic photoinhibition was > additive (synergistic) (Negri et al 2011)
- A 1.5-fold increase in dark respiration of an adult coral when co-exposed to diesel WAF and elevated temperature (Kegler et al. 2015).
- Concentration-dependent antagonistic effect of copper and reduced salinity (Alutoin et al 2001).
- A negative synergistic effect of temperature and nickel on growth rate, additive effect on respiration rate (Biscere et al. 2017).
- Additive or synergistic influence of warming seawater and pollutant exposure in the process of coral bleaching (Brown et al. 2000).
- Additive impacts on photosynthetic capacity when temperature and herbicide exposures were combined (Amid et al 2018).

Nalley et al. (2021), van Dam et al. 2011)

Next steps

- RISK= HAZARD x EXPOSURE; **Exposure** is a necessary condition for a **hazard** to become a **risk**
- Environmental monitoring studies and definitive studies on corals (multiple species, standardized methods, comprehensive analytical chemistry, breakdown products)
- Bottom-up assessment: single compounds → mixture → interactive effects
- Mechanistic studies to improve predictive capability, group chemicals by similar MOA
- Conservative guidelines that account for multiple stressors, sublethal impacts, compounding effects throughout the life cycle of an organism;
- Effects of long-term chronic exposure/stress are completely unknown

Current projects (UMCES & NSU)

Toxicity of octocrylene to *Acropora cervicornis:* standard test development

- Range finding, acute & chronic exposures (OECD guidelines)
- Flow-through design/continuous mixing of toxicant with seawater
- Appropriate positive & negative controls (copper, diuron)
- Comprehensive analytical chemistry
- ESA listed species
- Multiple endpoints

Occurrence & potential impacts of UV filters in *Acropora cervicornis*

- Three offshore and one onshore nursery in south Florida
- Paired seawater (surface and coral depth) and tissue samples
- Screening for 13 UV filters in water and tissue samples
- Temporal variability, before/after predicted spawning
- Matched genotypes between nurseries
- Comparison to coral fecundity