Amendment to original submission.

List of navigable water ways whose biological/ecological receptors and structures that can be impacted by sunscreens (oxybenzone and octinoxate) as a result of waste-water discharge (point and non-point sources), swimmer contamination, and/or from aerosol spray discharges from boaters and inflatable and rigid personal crafts (e.g., inflatable tubes, canoes, kayaks, paddle boards), all from the use of over-the-counter sunscreen SPF products. Contamination of these bodies of waters threaten subsistence fishers and USDA and National Marine Fisheries Service recognized fisheries in all the state listed in this amendment.

State of California

1. Smith River
2. Klamath River
3. Trinity River
4. Salmon River
5. Redwood Creek
6. Mad River
7. Sacramento river
8. Feather River
9. American River
10. Pit River
11. San Joaquin River
12. Mokelumne River
13. Calaveras River
14. Stanislaus River
15. Toulumne River
16. Merced River
17. Kings River
18. Kaweah River
19. Rule River
20. Kern River
21. Pajaro River
22. Salinas River
23. San Dieguito River
24. San Diego River
25. Santa Maria river
26. Santa Ynez River
27. Santa Clara River
28. Ventura River
29. Los Angeles River
30. San Gabriel River
31. Santa Ana River
32. Santa Margarita River
33. San Luis Rey River

34 Yuba River: "Some Yuba River Lovers are noticing an oily film on the water. While it may be the result of anything from gas to naturally occurring bacteria, the culprit is likely sunscreen because the film is most often visible at busy river crossings where lots of people gather. Many of the thousands of river visitors apply sunscreen before they swim, and that sunscreen often contains chemicals such as oxybenzone and octinoxate. But there are other environmentally friendly options. South Yuba River Citizens League Executive Director Melinda Booth says, "We know that some chemicals in sunscreen are detrimental to freshwater organisms, including fish, which is why we are urging visitors to choose UPF clothing or reef safe sunscreen when they head to the river…"

-https://www.theunion.com/ July 2, 2021

Lakes-

34. Tule Lake
35. Honey Lake
36. Mono Lake
37. Owens Lake
38. Tahoe Lake
39. Clear Lake
40. Shasta Lake
41. Almanor Lake
42. Oroville Lake
43. Havasu Lake
44. Berryessa Lake
45. Cachuma Lake
46. Donner Lake
47. New Melones Lakes
48. Sonoma Lake
49. Folsom Lake
50. Convict Lake
51. Eagle Lake
52. Castaic Lake
53. Silverwood Lake
54. Pyramid Lake
55. Big Bear Lake
56. Diamond Valley Lake
57. June Lake
58. Manzanita Lake
59. Virginia Lakes

State of Oregon

1. Columbia River
2. Williamette River
3. Deschutes River
4. McKenzie River
5. Snake River
6. Umpqua River
7. Oqyhee River
8. John Day River
9. Grade Ronde River
10. Sandy River
11. Klamath River
12. Rogue River
13. Santiam River
14. Metolius River
15. Clackamas River
16. Wallowa River
17. Chetco River
18. Crooked River
19. Malheur River
20. North Umpqua River
21. Donner and Blitzen River
22. Silvies River
23. Siuslaw River
24. Sixes River
25. Skipanon River
26. Smith River (McKenzie River)
27. Smith River (Umpqua River)
28. Snake River
29. South Fork Alsea River
30. South Fork Breitenbush River
31. South Fork Bull Run River
32. South Fork Burnt River
33. South Fork Clackamas River
34. South Fork Coos River
35. South Fork Coquille River
36. South Fork Crooked River
37. South Fork John Day River
38. South Fork Malheur River
39. South Fork McKenzie River
40. South Fork Roaring River
41. South Fork Rogue River
42. South Fork Salmon River
43. South Fork Sprague River
44. South Fork Umatilla River
45. South Santiam River
46. South Umpqua River
47. South Yamhill River
48. Succor Creek
49. Sprague River
50. Spring River (Deschutes River)
51. Spring River (North Umpqua River)
52. Steamboat Creek
53. Sycan River
54. Tenmile Creek (Coos County, Oregon)
55. Three Rivers
56. Tillamook River
57. Trask River
58. Treat River
59. Tualatin River
60. Tumalo Creek
61. Tumtum River
62. Umatilla River
63. Umpqua River
64. Walla Walla River
65. Wallooskee River
66. Wallowa River
67. Warm Springs River
68. Wenaha River
69. West Fork Hood River
70. West Fork Salmon River
71. West Fork Silvies River
72. West Fork Smith River
73. West Little Owyhee River
74. White River
75. Whitewater River
76. Whychus Creek
77. Wildcat Creek (Siuslaw River)
78. Wildhorse Creek
79. Willamette River
80. Williams River
81. Williamson River
82. Willow Creek
83. Wilson River
84. Winchuck River
85. Wind River
86. Wood River
87. Yachats River
88. Yamhill River
89. Yaquina River
90. Youngs River
91. Zigzag River
92. Burnt River
93. Calapooia River
94. Chetco River
95. Chewaucan River
96. Clackamas River
97. Clatskanie River
98. Clearwater River
99. Coos River
100. Luckiamute River

Lakes –

1. Crater Lake
2.Upper Klamath lake
3.Paulina Lake
4.Detroit Lake
5.Waldo Lake
6.Sparks Lake
7.Wallowa Lake
8.Odell Lake
9.East Lake Trillium Lake
10. Diamond Lake
11. Malheur Lake
12. Cascade Lakes
13. Lost Lakes
14. Elk Lake
15. Cultus Lake
16. Lake of the Woods
17. Crescent Lake
18. Albert Lake
19. Emigrant Lake
20. Timothy Lake
21. Fern Ridge Lake
22. Summer Lake
23. North Tenmile Lake
24. Agency Lake

State of Washington

1. American River
2. Ashnola River
3. Baker River
4. Bear River
5. Beckler River
6. Big Quilcene River
7. Black river
8. Bogachiel River
9. Bone River
10. Bumping River
11. Calawah River
12. Canyon River
13. Carbon River
14. Cedar River
15. Chehalis Rover
16. Chelan River
17. Chewuch River
18. Chilliwack River
19. Chiwawa River
20. Cispus River
21. Clallam River
22. Cleanwater River
23. Columbia River
24. Colville River
25. Cowlitz River
26. Deep River
27. Deschutes River
28. Dewatto River
29. Dickey River
30. Dosewallips River
31. Duckabush River
32. Dungeness River
33. Duwamish River
34. East Twin River
35. Elk River
36. Elwha River
37. Wntiat River
38. Foss River
39. Gray Wolf River
40. Grays River
41. Green River
42. Greenwater River
43. Hamma hamma River
44. How River
45. Hoko River
46. Humptulips River
47. Kachess River
48. Kalama River
49. Kettle River
50. Klickitat River
51. Klickitat River
52. Lewis River
53. Little Pend Oreille River
54. Little Quilcene River
55. Little River
56. Little Spokane River
57. Little Wenatchee River
58. Little White Salmon River
59. Mad River
60. Mashel River
61. Methow River
62. Miller River
63. Muddy River
64. Naches River
65. Palouse River
66. Paradise River
67. Pilchuck River
68. Pratt River
69. Queets River
70. Sail River
71. Sammamish River
72. Satsop River
73. Sauk River
74. Skagit River
75. Skokomish River
76. Skookumchuck River
77. Spokane River
78. Stuck Rilver
79. Sultan River
80. Tahuya River

Lakes in Washington State that would be contaminated with oxybenzone and octinoxate because of non-point and point sources of sunscreen application and removal.

1. Lake Chelan
2. Lake Washington
3. Lake Sammamish
4. Lake Wenatchee
5. Lake Franklin D. Roosevelt
6. Crescent Lake
7. Keechelus Lake
8. American Lake
9. Little kachess Lake
10. Quinault Lake
11. Baker Lake
12. Potholes Reservoir
13. Snoqualmie Lake
14. Osoyoos Lake
15. Tapps Lake
16. Wallula Lake
17. Mowich Lake
18. Omak Lake
19. Coldwater Lake
20. Alder Lake

State of Hawaii

1. ‘Ohe’o Gulh Stream
2. Anahulu River
3. Hanalei River
4. Hanapepe River
5. Hanawi Stream
6. Hule’ia River
7. Lumaha’I River
8. Paheehee Stream
9. Waijee River
10. Waimea River (Kaua’i)
11. Waimear River (Oahu)
12. Honolii Stream
13. Honomu Stream

State of Delaware

1. Appoquinimink River
2. Blackbird Creek
3. Brandywine Creek
4. Board Creeek
5. Broadkill River
6. Choptank River
7. Christina River
8. Delaware River
9. Hershey Run
10. Indian River
11. Leipsic River Lingo
12. River Mill Creek
13. Mispillion Rover
14. Murderkill River
15. Naamans Creek
16. Naticoke River
17. Pepper Creek
18. Pocomoke River
19. St. Jones River
20. Sassafras River
21. Simons River
22. Smyrna River

State of Rhode Island

23. Abbott Run
24. Annaquatucket River
25. Ashway River
26. Barrington River
27. Beaver River
28. Blackstone River
29. Branch River
30. Carr River
31. Chepachet River
32. Chipuxet River
33. Chockalog River
34. Clean River
35. Congdon River
36. Flat River
37. Green Fall River
38. Hunt River
39. Kickamuit River
40. Maidford River
41. Maiford River
42. Maskerchugg River
43. Mattatucet River
44. Mill River
45. Mishnock River
46. Moosup River
47. Moshassuck River
48. Nipumuc River
49. North Branch Pawtuxet River
50. Palmer Rver
51. Pawcatuck River
52. Pawtuxet River
53. Peters River
54. Rine River
55. Pocasset River
56. Potowomut River
57. Providence River
58. Quaket River
59. Warren River
60. Wood River
61. Woonasquatucket River

State of Illinois

1. Mississippi River
2. Ohio River
3. Saline River
4. Wabash River
5. Embarras River
6. Vermilion River
7. Cache River
8. Big Muddy River
9. Marys River
10. Kaskaskia River
11. Wood River
12. Illinois River
13. La Moine River
14. Sangamon River
15. Spoon River
16. Mackinaw River
17. Red river
18. Fox River
19. Mazon River
20. Des Plaines River
21. DuPage River
22. Kankakee River
23. Edwards River
24. Rock River
25. Green River
26. Kyte River
27. Leaf River
28. Kishwaukee River
29. Pecatonica River
30. Sugar River
31. Plum River
32. Galena River
33. Sinsinawa River
34. Menominee River

Lakes in Illinois State that would be contaminated with oxybenzone and octinoxate because of non-point and point sources of sunscreen application and removal.

1. Lake Michigan
2. Lake Rend
3. Lake Shelbyville
4. Lake Egypt
5. Devils Kitch Lake
6. Lake Carlyle
7. Lake Kinkaid
8. Lake Clinton
9. Crab Orchard Lake
10. Lake Springfield
11. Cedar Lake
12. Lake Decatur
13. Lake Shabbona
14. Lake Horseshoe
15. Nippersink Lake
16. Taylorville Lake
17. Argyle Lake
18. Lake Glenn Shoals
19. Devil's Kitchen Lake
20. Lake Springfield
21. Lake Mattoon
22. Little Grassy Lake
23. Lake Evergreen
24. Lake Galena

State of Connecticut

1. Connecticut River
2. Farmington River
3. Housatonic River
4. Naugatuck River
5. Salmon River
6. Quinnipiac River
7. Quinebaug River
8. Shetucket River
9. Scantic River
10. Thames River
11. Shepaug River
12. Willimantic River
13. Norfolk River
14. Blackledge River
15. Farm River
16. Pomperaug River
17. Still River
18. Mount Hope River
19. Coginchaug River
20. Mianus River
21. Aspertuck River
22. Blackberry River
23. Rippowam River
24. Fivemile River
25. Pawcatuck River

Lakes in the State of Connecticut that would be contaminated with oxybenzone and octinoxate because of non-point and point sources of sunscreen application and removal.

1. Candlewood Lake
2. Lake Zoar
3. Lake Bantam
4. Lake Hayward
5. Lake Highland
6. Lake Hop Brook
7. Colebrook River Lake
8. Lake Winchester
9. Lake Wangumbaug
10. Lake Bashan
11. Lake Amston

State of Ohio

1.Ohio River
2.Cuyahoga River
3.Scioto River
4.Great Miami River
5.Little Miami River
6.Muskingum River
7.Maumee River
8.Olentangy River
9.Sandusky River
10. Chagrin River
11. Mohican River
12. Kokosing River
13. Stillwater River
14. Grand River
15. Conneaut Creek
16. Hocking River
17. Paint Creek
18. Tuscarawas River
19. Mad River
20. Clear Fork Mohican River
21. Auglaize River
22. Little Beaver Creek
23. Wabash River
24. Ashtabula River
25. Mahoning River
26. Vermillion River
27. Clanchard Rover
28. Black River
29. Killbuck Creek
30. Big Walnut Creek
31. Huron River
32. Licking River
33. Saint Marys River
34. Ohio Brush Creek
35. Shenango River

Lakes in Ohio State that would be contaminated with oxybenzone and octinoxate because of non-point and point sources of sunscreen application and removal.

1. Lake Erie
2. Lake Indian
3. Lake Mosquito Creek
4. Lake Tappan
5. Lake Senecaville
6. Lake Salt Fork
7. Lake Atwood
8. Lake Buckeye
9. Lake Punderson
10. Lake Cesar Creek
11. Lake Alum Creek
12. Lake Leesville
13. Pymatuning Reservoir
14. Lake Clendening
15. Loramie Lake

State of Indiana

1. Maumee River
2. St. Marys River
3. St. Joseph River
4. Galena River
5. Grand Calumet River
6. Little Calumet River
7. Deep River
8. Wabash River
9. Black River
10. Patoka River
11. White River
12. East Fork White River
13. Lost River
14. Muscatatuck River
15. Flatrock River
16. Driftwood River
17. Big Blue River
18. Eel River
19. Vermilion River
20. Salamonie River
21. Mississinewa River
22. Anderson River
23. Great Miami River
24. Blue River
25. Kankakee River
26. Iroquois River
27. Yellow River
28. Little Kankakee River
29. Black River
30. Driftwood River

Lakes in Indiana State that would be contaminated with oxybenzone and octinoxate because of non-point and point sources of sunscreen application and removal.

1. Lake Michigan
2. Lake Monroe
3. Lake Patoka
4. Lake Tippecanoe
5. Leon Lake
6. Freeman Lake
7. Maxinkuckee Lake

State of New York

1. Hudson River
2. Mohawk River
3. Delaware River
4. Saint Lawrence River
5. Genesee River
6. Raquette River
7. Susquehanna River
8. Sacandaga River
9. Ausable River
10. Oswegatchie River
11. East River
12. Chemung River
13. Schoharie Creek
14. Allegheny River
15. Niagara River
16. West Canada Creek
17. Wallkill River
18. Boreas River
19. Cohocton River
20. Saranac River
21. Bouquet River
22. Salmon River
23. Grass Rover Saint Regis Rover
24. Canisteo River
25. Hoosic River
26. Esopus Creek
27. Oswego River
28. Catskill Creek
29. Great Chazy River
30. Moose River
31. Batavia Kill Bog River
32. Beaver Kill
33. Croton River
34. Neversink River
35. Cedar River
36. Chatauqua Creek
37. Chateauguay River
38. Batten Kill
39. Ramapo River
40. Chenango River
41. Independence River
42. Cross River
43. Bronx River
44. Housatonic River
45. Tenmile River
46. Byram River
47. Mamaroneck River
48. Sheldrake River
49. Hutchinson River
50. Nissequogue River
51. Wading River
52. Peconic River
53. Carmans River
54. Connetquot River
55. Swan River
56. Hackensack River
57. Saw Mill River
58. Kisco River
59. Muscoot River
60. Titicus River
61. East Branch Croton River
62. Indian River
63. Cold Brook
64. Maltanner Creek
65. Mongaup River
66. Callicoon Creek
67. Tremper Kill
68. Platte Kill
69. Chemung River
70. Tioga River
71. Cornell Creek
72. Carrs Creek Brier Creek
73. Otego Creek
74. Bouquet River
75. Mettawee River
76. Chaumont River
77. Perch River
78. Roaring Brook
79. Buffalo River
80. Cattaraugus Creek
81. Canadaway Creek
82. Little Valley Creek
83. Olean Creek
84. Ischua Creek
85. Dodge Creek
86. Oswayo Creek

Lakes of New York

1. Lake Cayuga
2. Lake Erie
3. Lake Ontario
4. Lake Champlain
5. Lake Keuka
6. Lake Oneida
7. Lake George
8. Lake Canandaigua
9. Lake Placid
10. Lake Saratoga
11. Lake Adirondack
12. Lake Black
13. Lake Cranberry
14. Lake Raquette
15. Lake Tiorati
16. Lake Forked
17. Lake Lower Saranac
18. Lake Abanakee
19. Lake Avalanche
20. Lake Skaneateles

State of Maryland

1. Potomac River
2. Patuxent River
3. Patapsco River
4. Susquehanna River
5. Choptank River
6. Monocacy River
7. Nanticoke River
8. Gunpowder River
9. Chester River
10. Anacostia River
11. Pocomoke River
12. Youghioghe River
13. Wicomico River
14. Tred Avon River
15. Antietam Creek
16. Casselman River
17. Sassafras River
18. Elk River
19. Conocoche Creek
20. Rhode River
21. St. George River
22. St. Martin River
23. St. Mary's River
24. Wye River
25. Magothy River
26. Savage River
27. Manokin River
28. Hawlings River
29. Port Tobacco River
30. Marshyhope Creek

State of South Carolina

1. Edisto River
2. Saluda River
3. Santee River
4. Great Pee Dee River
5. Congaree River
6. Catawba River
7. Waccamaw River
8. Broad River
9. Chattooga River
10. Lynches River
11. Wateree River
12. Black River
13. Tugaloo River
14. Pacolet River
15. Enoree River
16. Combahee River
17. Cooper River
18. Tyger River
19. Reedy River
20. Ashley River
21. Lumber River
22. Ashepoo River
23. Chauga River
    Salkehatchie River
24. Wando River
25. Sampit River
26. Stono River
27. Rocky River
28. Four Hole Swamp
29. Horsepasture River
30. Sandy River

State of Virginia

1. James River
2. Potomac River
3. Rappanhannock River
4. New River
5. Shenandoah River
6. Jackson River
7. Tye River
8. Buffalo River
9. Rivanna River
10. Nottoway River
11. Pamunkey River
12. Rapidan River
13. Dan River
14. Cowpasture River
15. Roanoke River
16. Mattaponi River
17. Powell River
18. Clinch Rivery
19. Chickahominy River
20. Holston river
21. Guest River
22. Piankatank River
23. Russel Fork
24. Craig Creek
25. Hazel River
26. Moormans River
27. Calfpasture River
28. Banister River
29. Bullpasture Riover
30. Occoquan River
31. Maury River
32. Smith River
33. Pound River
34. Rockfish River
35. Difficult Run
36. Four Mile Run
37. Passage creek
38. Corrotoman River
39. Chesapeake Bay
40. Great Wicomico River

State of Massachusetts

1. Connecticut River
2. Charles River
3. Merrimack River
4. Deerfield River
5. Nashua River
6. Ipswich River
7. Westfield River
8. Millers River
9. Concord River
10. Taunton River
11. Hoosic River
12. Quaboag River
13. Blackstone River
14. Assabet River
15. Chicopee River
16. Housatonic River
17. Ware River
18. Mystic River
19. Sudbury River
20. Squannacook River
21. Nissitissit River
22. Konkapot River
23. Scantic River
24. Quequechan River
25. Shawseen River
26. Mashpee River
27. Muddy River
28. Eel River
29. Quinapoxet River
30. Powwow River
31. Stillwater River
32. Otter River
33. Segreganset River
34. Mill River
35. Indian Head River

State of Montana

1. Missouri River
2. Yellowstone River
3. Madison River
4. Gallatin River
5. Jefferson River
6. Big Hole River
7. Smith River
8. Boulder River
9. Bighorn River
10. Blackfoot River
11. Stillwater River
12. Bitterroot River
13. Flathead River
14. Beaverhead River
15. Ruby River
16. Clark Fork
17. East Gallatin River
18. Kootenay River
19. Sun River
20. Musselshell River
21. Red Rock River
22. Dearborn River
23. Yaak River
24. Swan River
25. Milk River
26. Teton River
27. Tongue River
28. Poplar River
29. Two Medicine River
30. Thompson River

State of Maine

1. Kennebec River
2. Penobscot River
3. Androscoggin River
4. Saint John River
5. Arrostook River
6. Saco River
7. Sheepscot River
8. Carrabassett River
9. Dead River
10. Narraguagus River
11. Saint Croix River
12. Royal River
13. Fish River
14. Piscataquis River
15. Saint George River
16. Big Black River
17. Saint Francis River
18. Ossipee River
19. Damariscotta River
20. Ellis River
21. Eastern River
22. Union River
23. Sandy River
24. Mousam River
25. Stroudwater River
26. Machias River
27. Nezinscot River
28. Roach River
29. Pleasant River
30. Salmon Falls River

State of Michigan

1. Manistee River
2. Huron River
3. Au Sable River
4. Saint Joseph River
5. Grand River
6. Miskegon river
7. Kalamazoo River
   Rifle River
8. Menominee River
9. Ontogangon River
10. Betsie River
11. Flat River
12. Saint Clair River
13. Boardman River
14. Pine River
15. White River
16. Two-Hearted River
17. Thornapple River
18. Detroit River
19. Raisin River
20. Sturgeon River
21. Shiawassee River
22. Escanaba River
23. Saginaw River
24. Flint River
25. Cass River
26. Manistique River
27. Clinton River
28. Jordan River
29. Fox River
30. Brule River

State of Wisconsin

1. Wisconsin River
2. Mississippi River
3. Chippewa River
4. Saint Croix River
5. Namekagon River
6. Rock River
7. Fox River
8. Bois Brule River
9. Peshtigo River
10. Menominee River
11. Milwaukee River
12. Baraboo River
13. Wolf River
14. Kickapoo River
15. Red cedar River
16. Bad River
17. Pecatonica River
18. Oconto River
19. Pike River
20. Nemadji River
21. Waupaca River
22. Grant River
23. Eau Claire River
24. Root River
25. Apple River
26. Kinnickinnic River
27. La Crosse River
28. Sugar Rver
29. Saint Louis River
30. Popple River

State of New Mexico

1. Animas River
2. Rio Grande
3. Pecos River
4. Canadian River
5. Cimarron River
6. San Juan River
7. San Francisco River
8. San Jose River
9. Gila River

State of Colorado

1. South Platte River
2. Yampa River
3. White River
4. San Juan River
5. Dolores River
6. Rio Grande River
7. Gunnison River
8. Arkansas River
9. Fraser River
10. Colorado River
11. Green River
12. Eagle River

Description of the Affected Environment

Oxybenzone and octinoxate pollution can impact a number of different marine and aquatic ecosystems. The major sources of contamination can come directly from point and non-point sources of sewage discharges, beachgoers and swimmers, as well as dissolution of atmospheric volatile organic carbon fraction into bodies of water. Oxybenzone is thought to persist in relevant surface waters from several weeks and months to 3.4 years (e.g., Vione et al 2013; O'Malley et al 2021).

Sewage point and non-point sources. Oxybenzone and octinoxate can be absorbed through the skin, and discharged from the body in urine. Consumers using skin-applied sunscreens will also wash their bodies, draining residues into the sewage (Giokas et al 2007). Point sources of oxybenzone/octinoxate environmental contamination include municipal or system-residential discharges, as well as water vessel discharges of both black and grey waters (Liu et al 2012; Tsui et al 2014a,b; Ramos et al 2016; Molins-Delgao et al 2017; Wang and Kannan 2017; Wu et al 2018; O'Malley et al 2020). Sludge and biosolids derived from sewage are also a source for environmental contamination, especially when these sludges are applied to agricultural fields or used in potting soils (Abril et al 2020). Livestock fed contaminated waters/feed containing oxybenzone and other UV filters (as well as parabens) from human sludge can be found in livestock effluent (Liu 2018).

Swimmers with sunscreens applied to their skin will shed the sunscreen contaminants into the aqueous environment.

Aerosols. Contamination via aerosol routes happen predominantly through the use of aerosol-based sunscreen sprays (Wan et al 2016; Pegoraro et al 2020), though indoor air contamination can be derived from sunscreen lotion and spray dust (Negreira et al 2009; Wang et al 2013). Oxybenzone and octinoxate can be significant factors in volatile organic carbon pollution (Pegoraro et al 2015; Pegoraro et al 2018). Atmospheric contamination either as an individual volatile or in a nanotized/microtized mist can travel hundreds of meters from the point of product discharge. This oxybenzone/octinoxate atmospheric deposition can occur on a body of water, or on a terrestrial surface (e.g., sand on beach over a sea turtle nest) (Sankoda et al 2015 Tarazona et al 2014; Capela et al 2019).

Freshwater environments. Creeks, rivers and lakes can be contaminated with oxybenzone/octinoxate (Balmer et al 2005; Fent et al 2005). Every body of water that receives sewage discharge is potentially contaminated with oxybenzone/octinoxate. This includes alpine lakes to South Florida drainage canals, as well as the Great Lakes of North America. Recreational "tubers" and surface craft can use sunscreen products, and contaminate rivers, large streams, and coastal environments of lakes.

Marine Environments. A variety of marine ecosystems can be contaminated with oxybenzone/octinoxate. The most common example of this contamination are coral reefs areas, as well as other nearby ecosystems such as mangroves and seagrass beds (e.g., Northern Mariana Islands, Guam, Hawaii, Florida, Puerto Rico, U.S. Virgin Islands). Other marine ecosystem can be contaminated, especially near dense municipal areas, as well as popular tourism destinations, including the saltmarsh estuaries that range from the coastlines of Delaware to Northern Florida, the Kelp Forests of Washington to California (e.g., Channel Islands), seagrass beds of Texas, Louisiana, Mississippi, Florida, and Georgia, and even the arctic coastline of Barrow, Alaska (Ribeiro et al 2017; Tsui et al 2015). Several U.S. National Parks (Hawaii, U.S. Virgin Islands, North Carolina, Florida) and U.S. National Marine Sanctuaries (Hawaii, Florida) are known to possess environmental contamination of both oxybenzone and octinoxate.

Contamination of subsurface (ground) waters should also be recognized (Jurado et al 2014; Careghini et al 2014). This contamination can affect the delicate subterranean ecosystems, as well as be a means of transport of these contaminants if these waters manifest as submarine ground discharges, or used as a water source for agricultural or lawn irrigation or for potable drinking water.

A novel anthropogenic environment that can be highly contaminated are swimming pools and hot tubs, as a result of both skin-derived contamination and urination in these bodies of water. Oxybenzone and avobenzone can react with chlorine and bromine residues to result in chlorinated and/or brominated oxybenzone and avobenzone derivatives. These residues are much more toxic than the parent compounds (Manasfi et al 2015; Yimazcan et al 2015; Ekowati et al 2016; Zhang et al 2016; Lima et al, 2019; Lempart et al 2018; Li et al 2020; Mokh et al 2021)

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Known Areas of Oxybenzone and Octinoxate Contamination

Areas within the United States with known environmental contamination levels of oxybenzone and octinoxate.

Methods:

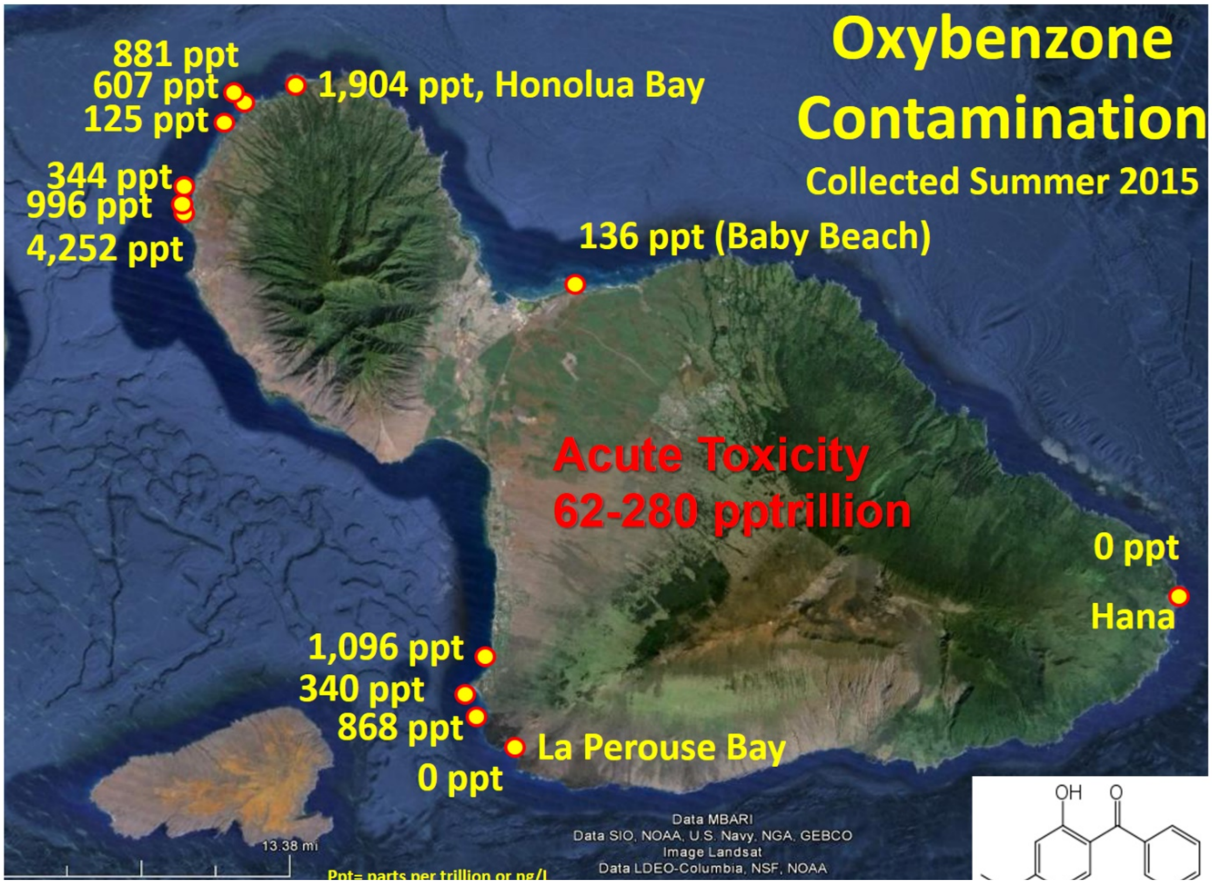
Water Samples: Seawater samples in 2009 in the U.S. Virgin Islandswere collected using pre-cleaned one-liter amber glass bottles with Teflon lined lids (I-Chem, 300 series, VWR). Seawater samples were extracted using C-18E cartridges (500mg, 6mL Phenomenex Inc.) on a vacuum manifold (Phenomenex Inc.). Cartridges were conditioned with 5 mL of methanol, then 5 mL of water, after which the seawater samples were then added to the column. Following extraction, the cartridges were dried for 10 minutes, capped and frozen until processed. The cartridges were eluted with 2 mL acetone followed by 2 x 5 mL dichloromethane. The extracts were evaporated to dryness under a gentle stream of nitrogen. Then 50 uL of MSTFA (N-Methyl-N-(trimethylsilyl) trifluoroacetamide, Sigma-Aldrich) was added, capped, vortexed for 30 seconds, and heated at 80°C for 30 minutes. Extracts were transferred to gas chromatography vials with a rinse step to a final volume of 1 mL and the internal standard was added. Percentage recovery for all 8 target analytes using this method with seawater was above 95%.

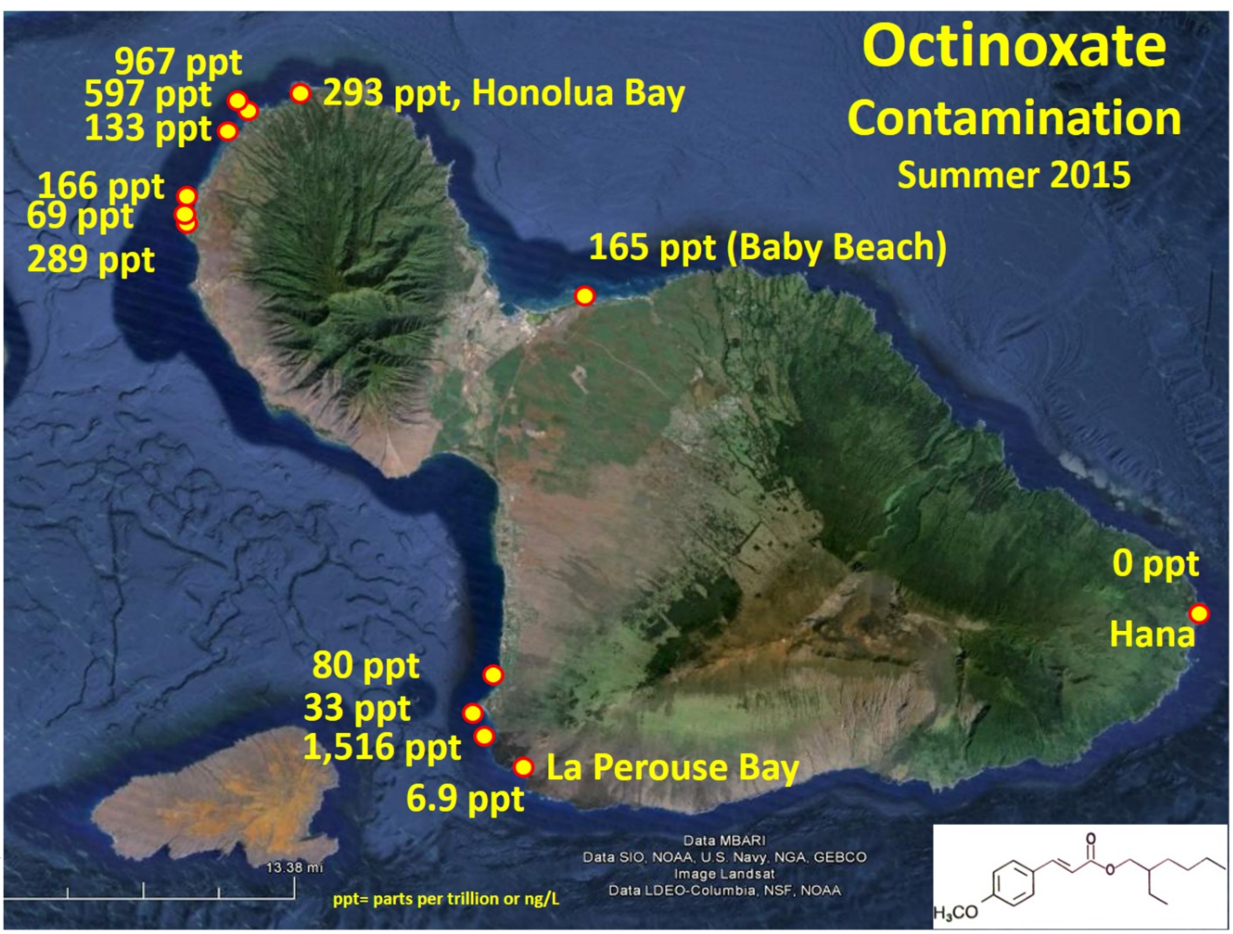
Seawater samples from at all other times from Hawaii, North Carolina, Florida were collected using pre-cleaned amber or clear glass bottles with Teflon lined lids (I-Chem, 300 series, VWR). Samples were extracted using C-18E cartridges (500mg, 6mL Phenomenex Inc.) on a vacuum manifold (Phenomenex Inc.). Cartridges were conditioned as indicated in the previous paragraph, and eluted with 5 mL of methanol. For LC-MS analysis, samples were run on an AB_SCIEX 5500 QTRAP Triple Quadrupole Hybrid Linear Ion Trap Mass Spectrometer with a Spark Holland Symbiosis HPLC for analytical separation. The analytes were measured with MRM (multiple reaction monitoring) followed by switching to ion trap functionality (Q3- LIT) to confirm the fragmentation pattern of the MRMs. The source was set at 700°C and the gasses were set to 60 arbitrary units of nitrogen. The curtain gas was set at 45 arbitrary units and all MRMs were optimized using infusion based introduction of analytical standards. Analytical separation was performed using a Phenomenex Hydro RP 4.6 x 50 2.6 µm particle size stationary phase, with the mobile phase composed of methanol and water with the addition of 0.1% formic acid and 5mM ammonium acetate in both phases. The flow rate was set at 0.9 mL per minute and a ballistic gradient and re-equilibration was run over 5 minutes. Percentage recovery for target analytes was above 85%, Limit of Detection was 100 pptrillion (ng/L) , and Quantitative Limit of Measurement was 5 ppbillion (µg/L).

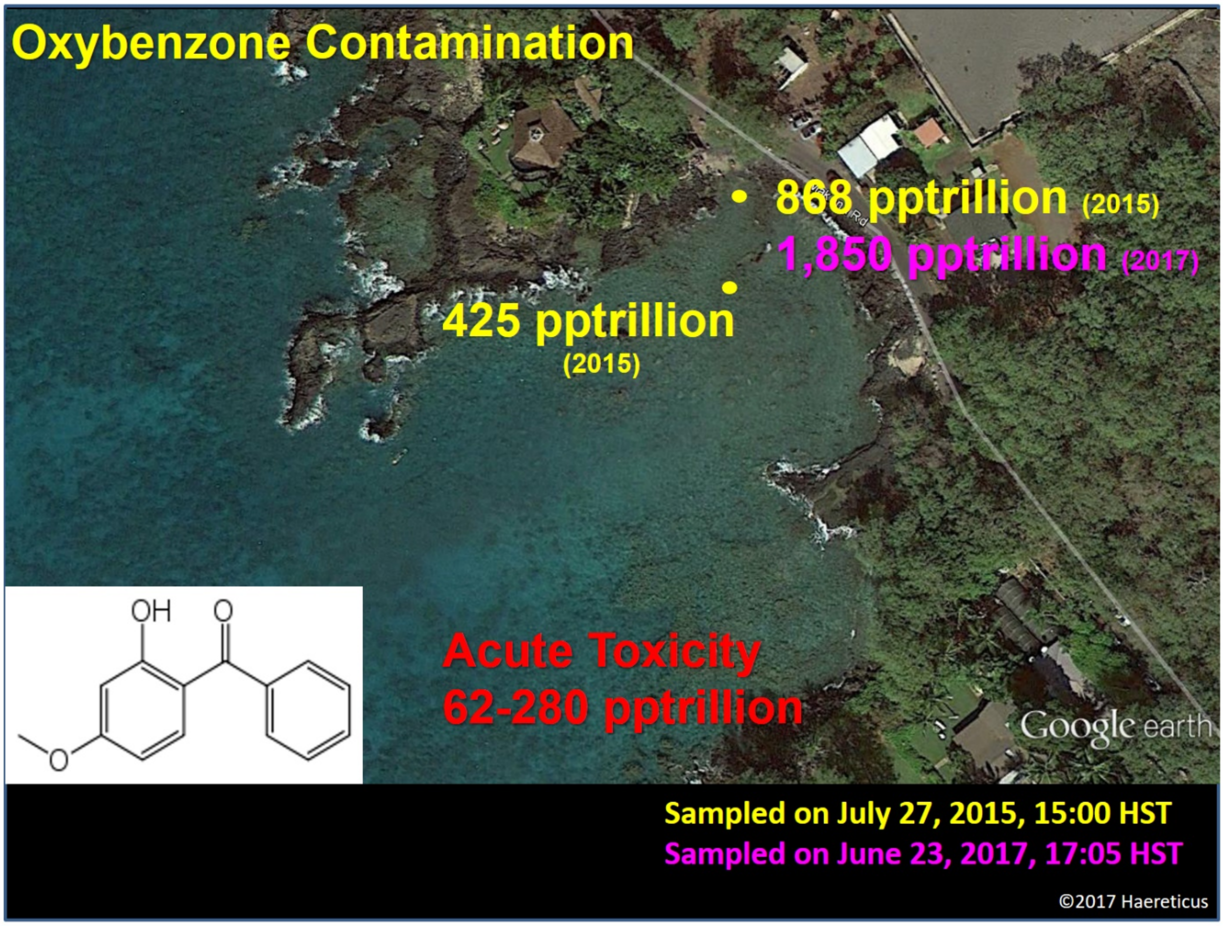
All water samples at all U.S. locations were sampled roughly 30 centimeters below the surface of the water.

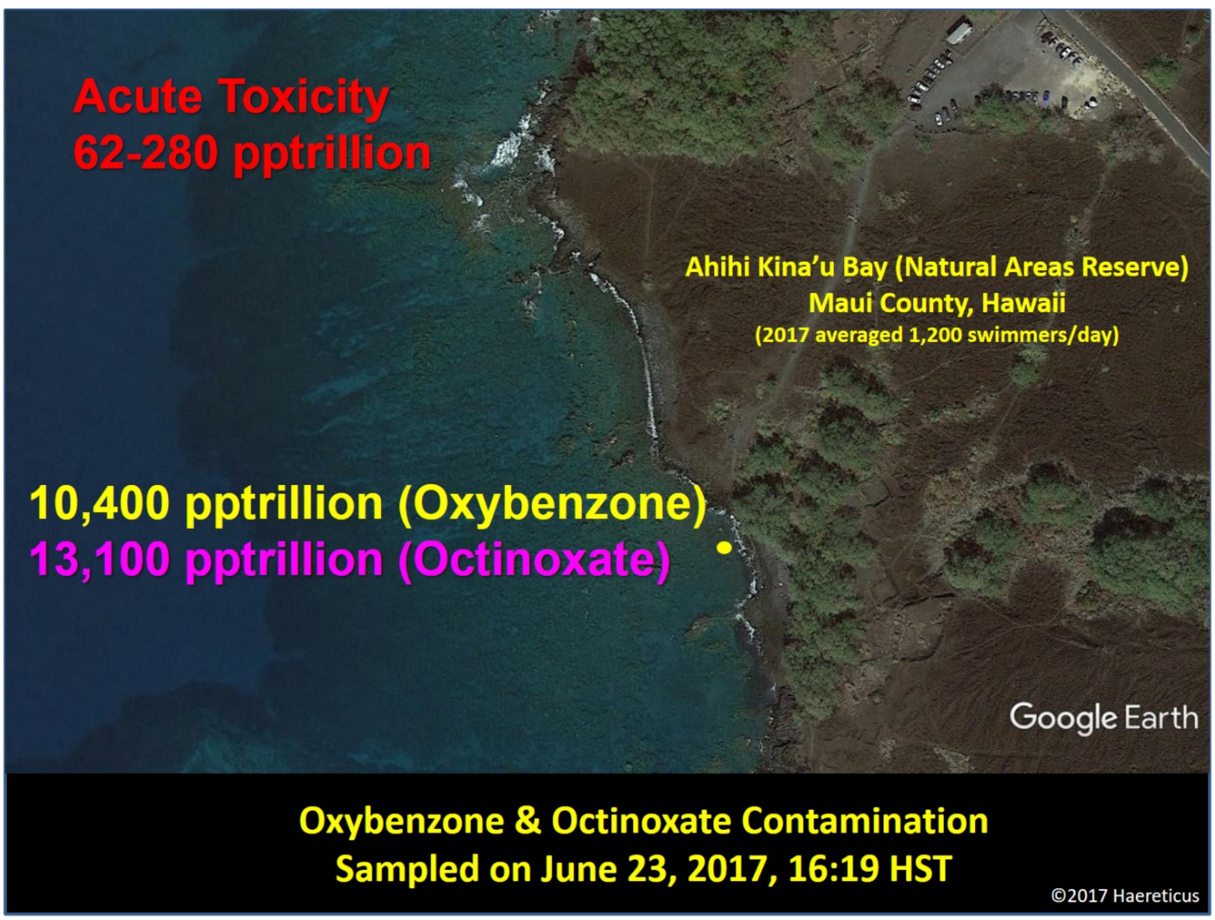
Sand samples were collected from the surface of the beach area within a 10 cm x 10 cm gridded area, collecting the top ~5mm of surface layer into a pre-cleaned PFA-bag, and then frozen until extraction. Extraction was conducted using either an Accelerated Solvent Extraction method or using a standard additions method (for details of either method, contact cadowns@haereticus-lab.org). Analytical separation and detection used an HPLC-mass spectrometer.

Locations:
Maui County, State of Hawaii

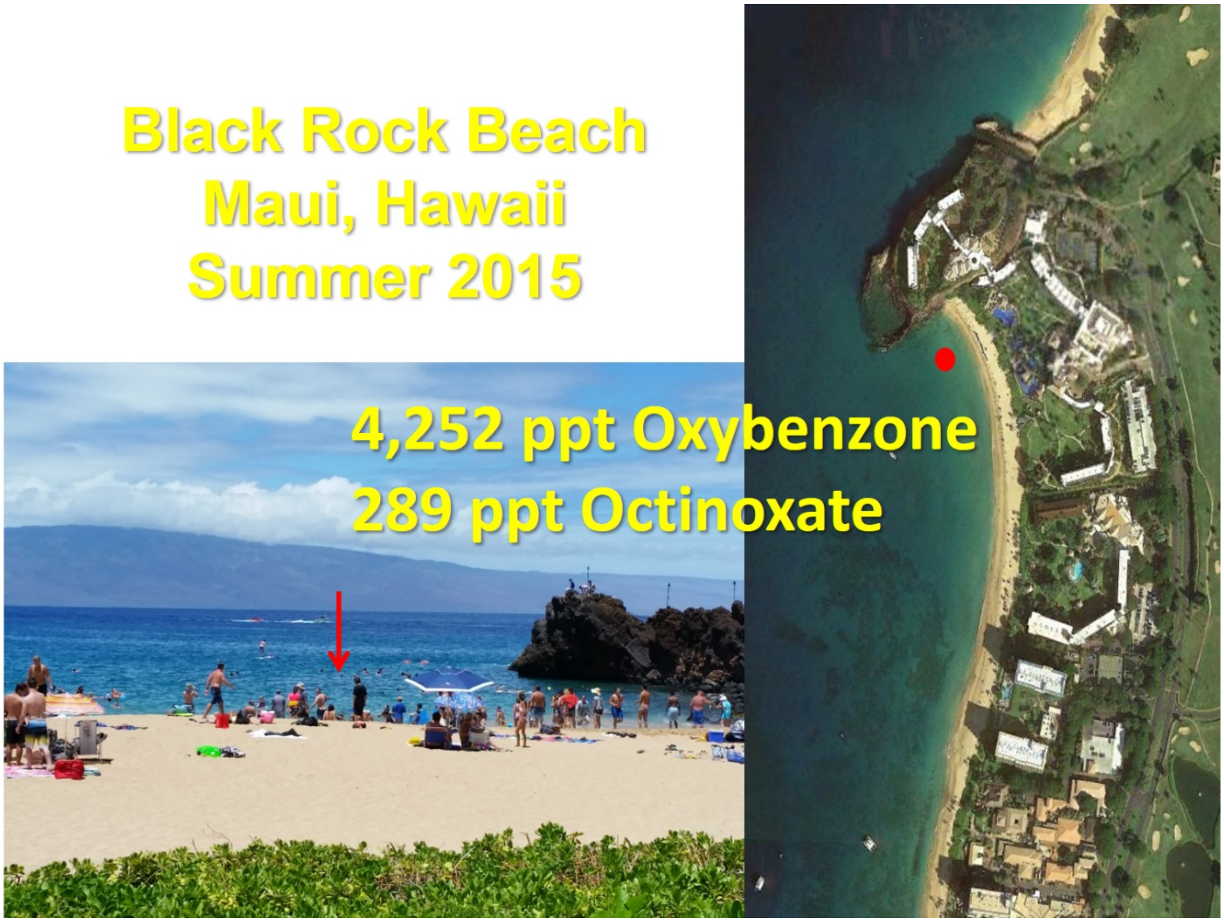


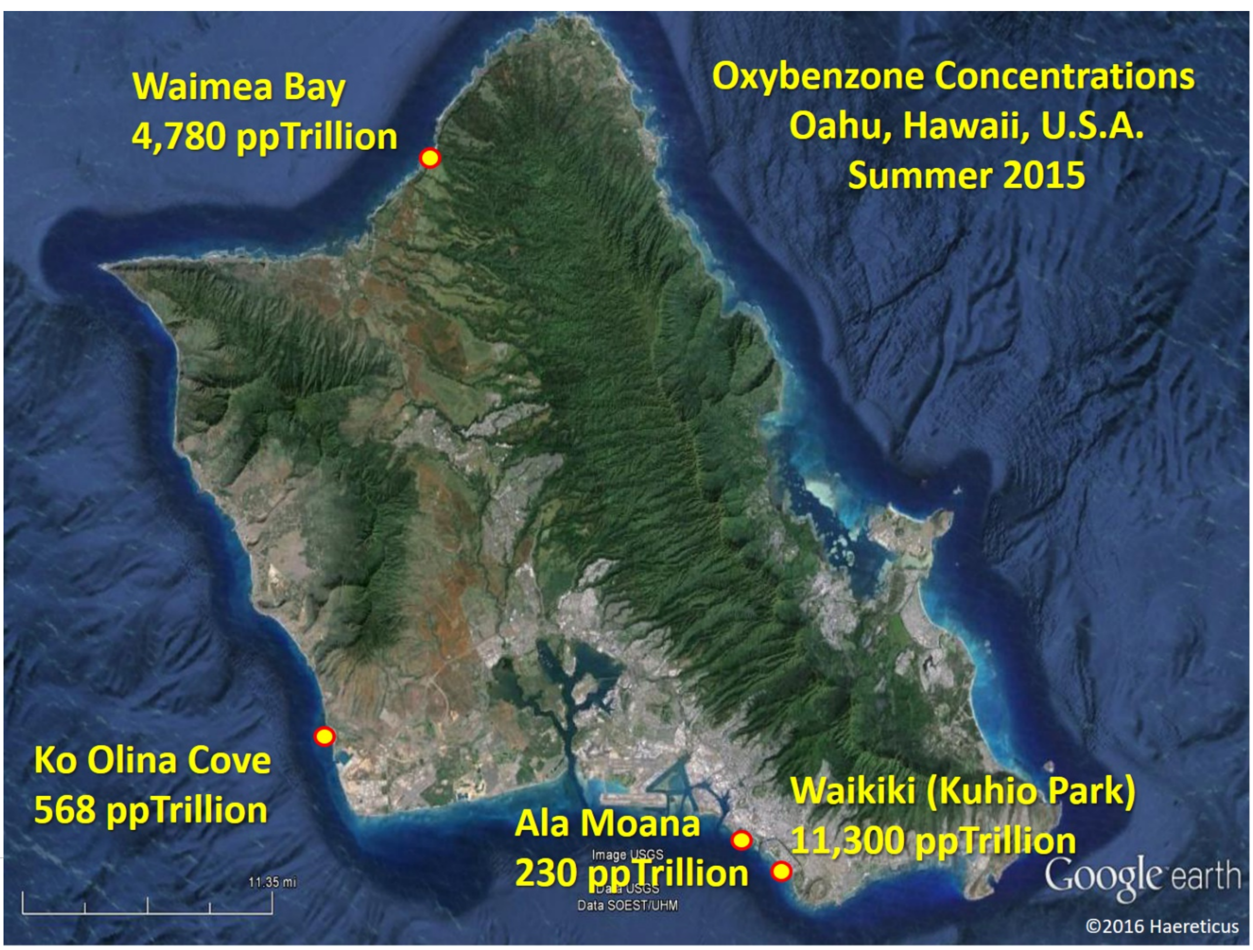



Oxybenzone Contamination
868 pptrillion (2015)
1,850 pptrillion (2017)
425 pptrillion
(2015)
OH
O
O
Acute Toxicity
62-280 pptrillion
Google earth
Sampled on July 27, 2015, 15:00 HST
Sampled on June 23, 2017, 17:05 HST
©2017 Haereticus

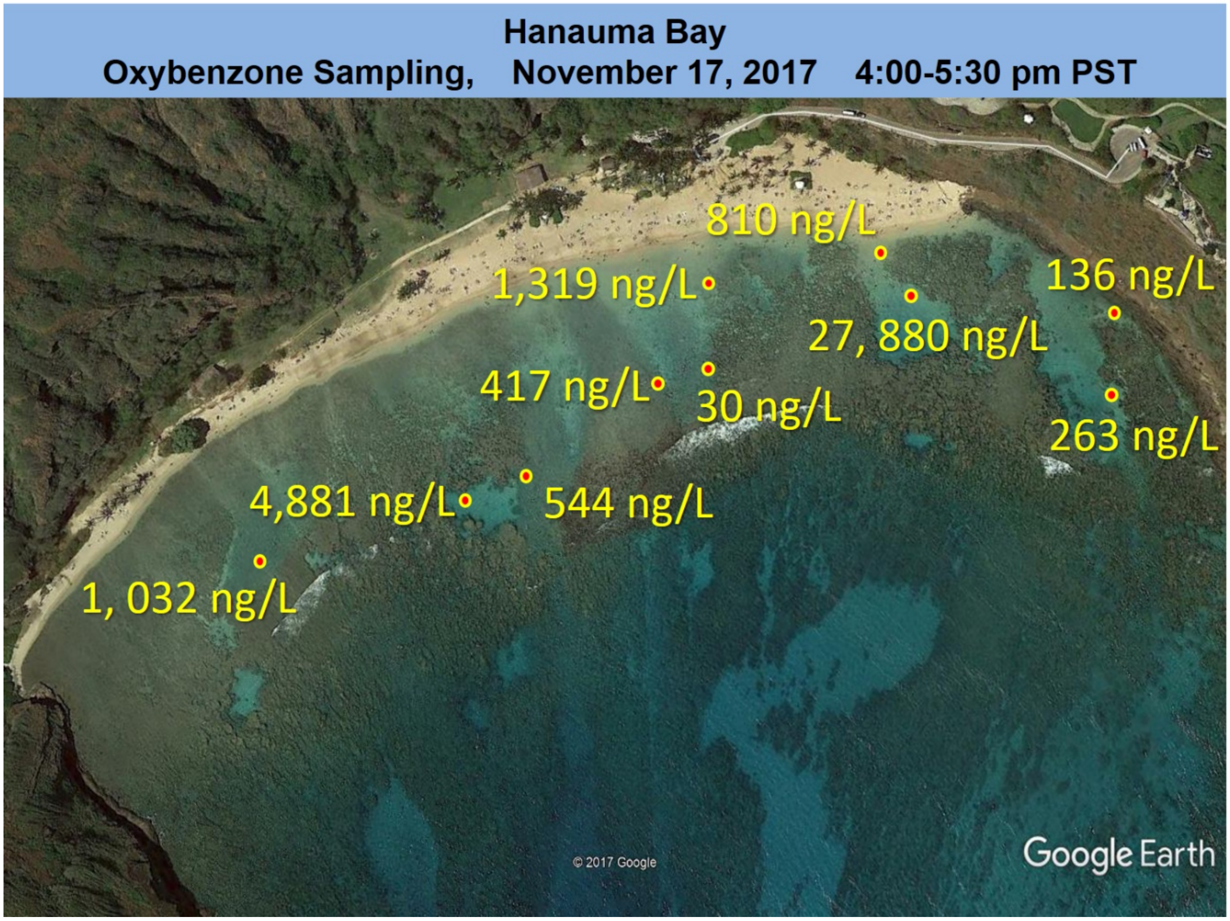

Acute Toxicity
62-280 pptrillion
Ahihi Kina'u Bay (Natural Areas Reserve)
Maui County, Hawaii
(2017 averaged 1,200 swimmers/day)
10,400 pptrillion (Oxybenzone)
13,100 pptrillion (Octinoxate)
Google Earth
Oxybenzone & Octinoxate Contamination
Sampled on June 23, 2017, 16:19 HST
©2017 Haereticus

Sampled in Kaanapali area in Maui County, Hawaii

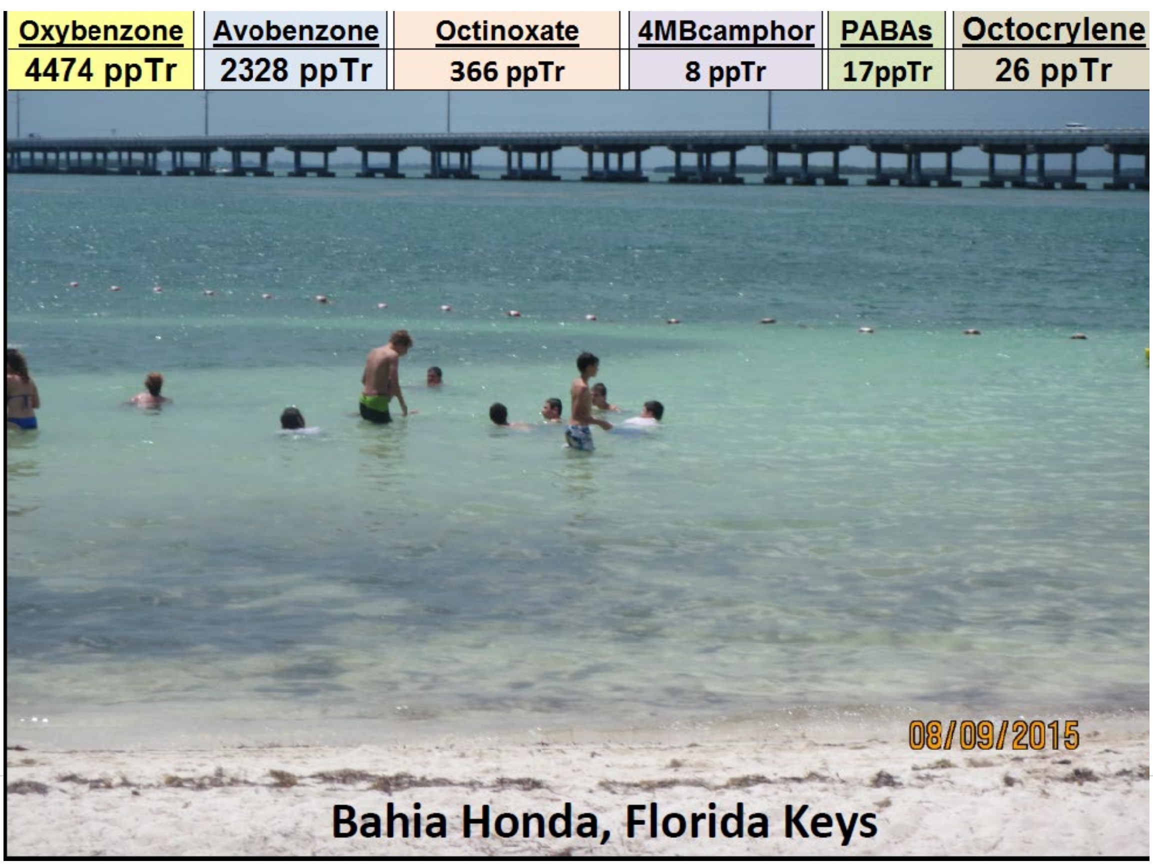




Sample within the City of Honolulu, on the island of Oahu, Hawaii



Sampled in the Florida Keys, Florida

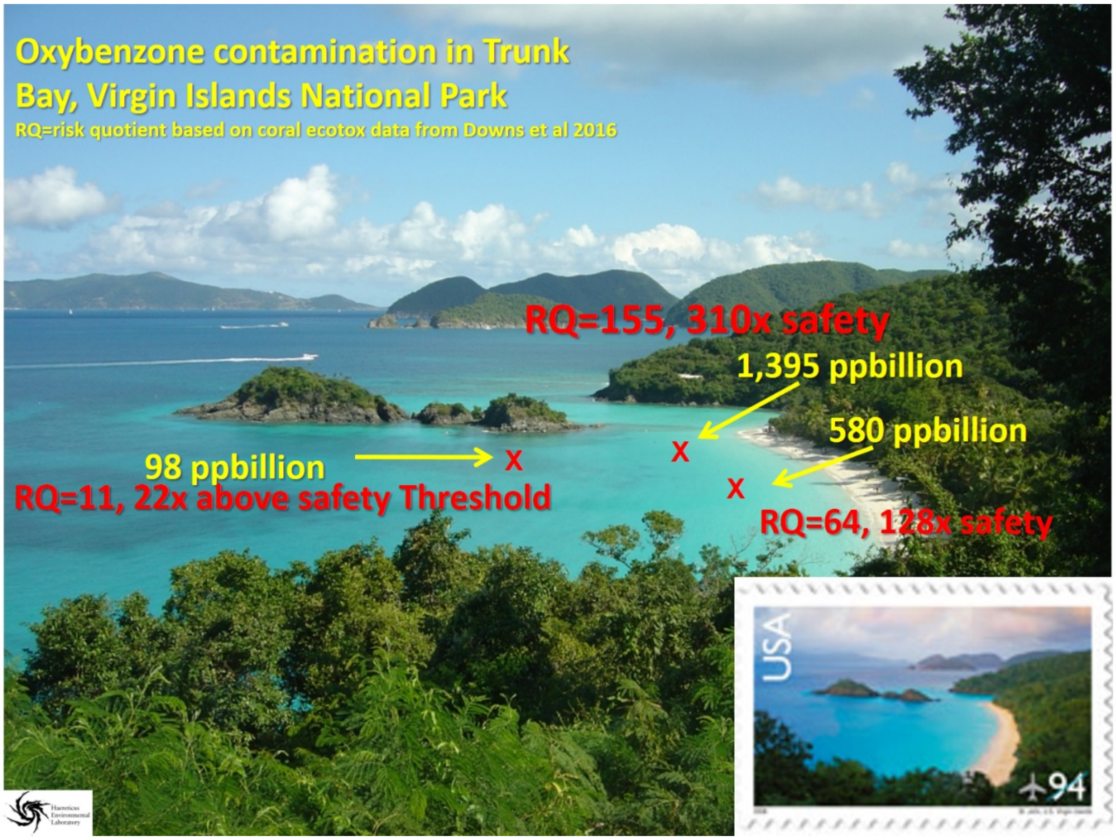


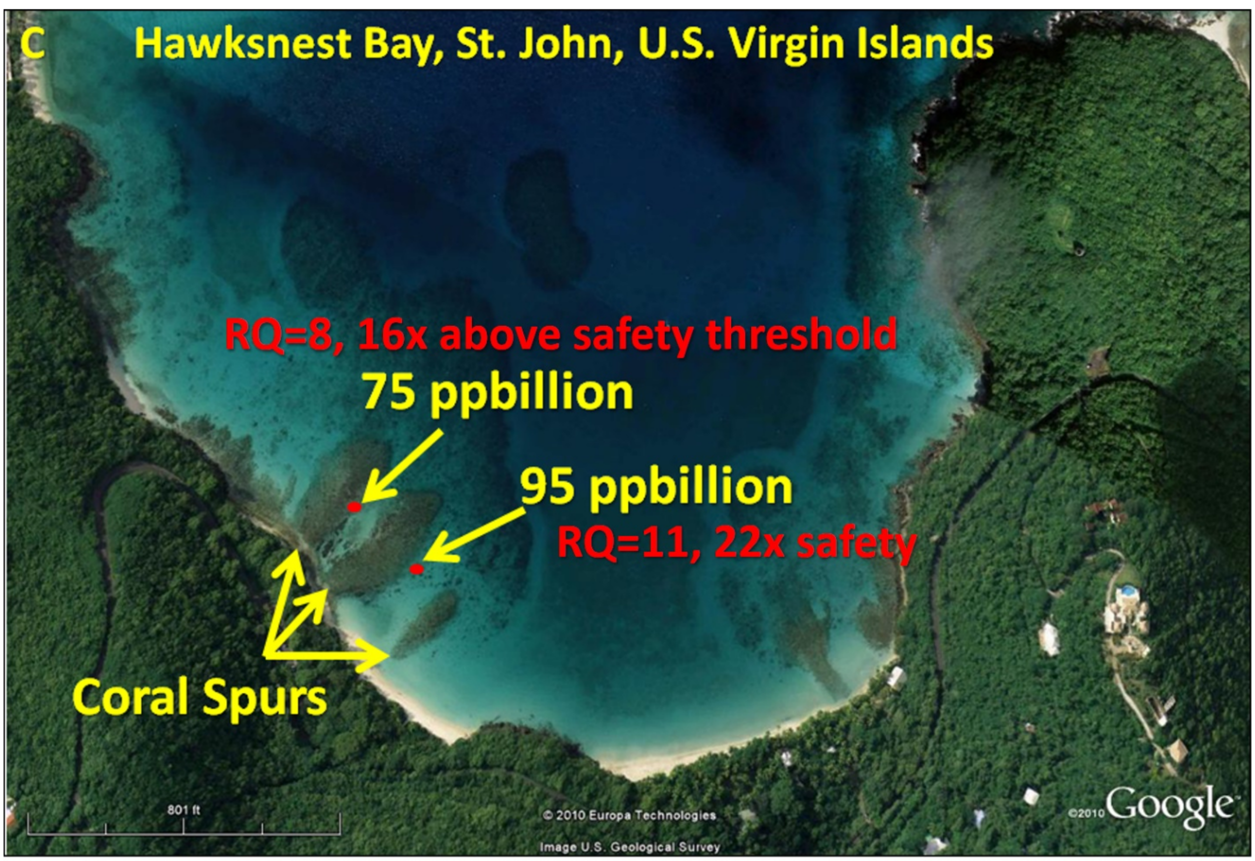
	Oxybenzone	Avobenzone	EHMcinnamate	4MBcamphor	PABAs	Octocrylene
Miami Beach	15,425 pptrillion	1,198 pptrillion	311 pptrillion	29 pptrillion	24 pptrillion	251 pptrillion

Environmental Contamination
U.S. Virgin Islands

Location		Oxybenzone	Avobenzone	Octinoxate	4MBcamphor	PABAs	Octocrylene
U.S. Virgin Islands							
	Buck Island West Beach	1,348	128	148	11	3	65
	Buck Island Underwater Trail	56	334	76	5	10	35
	Rainbow Beach, St. Croix	2,236	40	140	4	5	86

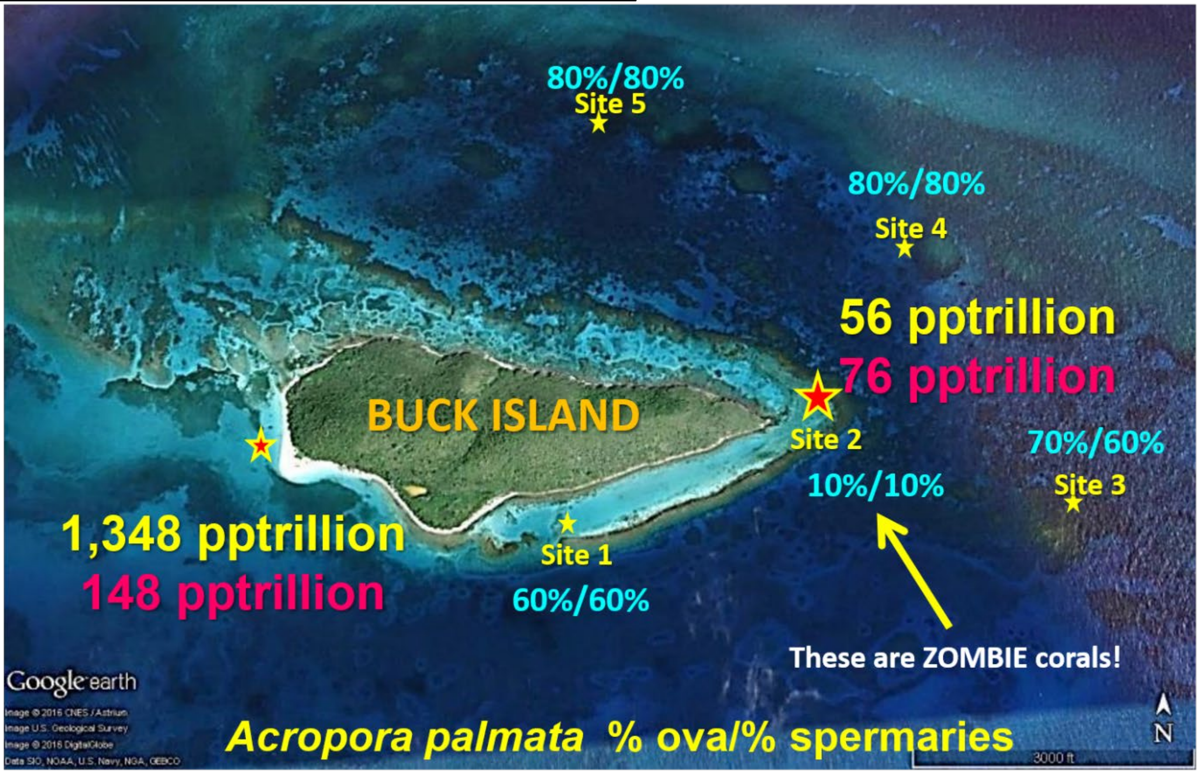
All values are in parts per trillion
Nanograms/liter
Sampled in Summer of 2015





Oxybenzone contamination

Oxybenzone Contamination Octinoxate Contamination



Sampled in 2015 by U.S. NOAA and U.S. NPS

Impacts to threated or endangered species

Because oxybenzone and octinoxate are ubiquitous consumer products, and the eventual transport and fate means they contaminate the environment, many aquatic, marine, and fowl species are at risk (Wang et al 2021).

There have been studies demonstrating that UV filters can contaminate marine mammals, such as dolphins (Gago-Ferrero et al 2013). Some of these UV filters, such as octocrylene contaminate the mother, and transfer octocrylene to its infant via breast milk (Alonso et al 2015). This is phenomenon is similar to what is observed with other mammal species, including rodents and humans (Hany and Nagel 1995; Molins-Delgado et al 2018). The danger of oxybenzone contamination of breasts and breastmilk is that it may result in a pathology that alters expression of milk volume, resulting in caloric and nutritional deficiencies in the cetacean or pinniped (Matouskova et al 2019; Altamirano et al 2020). Anything that reduces the survival and reproductive fitness of a population/species of an ESA-listed species is considered a threat.

Protect species of marine mammals at risk in the U.S.:

Marine Mammals

Scientific Name	**Common Name**
Trichechus manatus	West Indian Manatee
Pseudorca crassidens	False Killer Whale
Orcinus orca	Killer whale
Erignathus barbatus	Bearded Seal
Neomonachus schauinslandi	Hawaiian monk seal
Eumetopias jubatus	Stellar sealion
Balaenoptera physalus	Fin whale
Balaenoptera borealis	Sei whale
Eubalaena glacialis	North Atlantic Right Whale

Protect species of reptiles at risk in the U.S.:

There has been one study demonstrating that sea turtles can be contaminated by oxybenzone/octinoxate, and that these can result in inflammatory responses, as well as endocrine disruption (Cocci et al 2020). There are a number of aquatic and marine species that are at risk of exposure, hence at risk for toxicological effects:

Reptile Species

Scientific Name	**Common Name**
Crocodylus acutus	American crocodile
Eretmochelys imbricata	Hawksbill sea turtle
Dermochelys coriacea	Leatherback sea turtle
Lepidochelys kempii	Kemp's ridley sea turtle
Nerodia clarkii taeniata	Atlantic salt marsh snake
Alligator mississippiensis	American alligator
Caretta caretta	Loggerhead sea turtle
Ambystoma bishopi	Reticulated flatwoods salamander

Chelonia mydas	Green sea turtle

Protect species of birds at risk in the U.S.:

Oxybenzone and octinoxate are known to contaminate birds of a broad range of species, including raptors (Gonzalez-Rubio et al 2020; Oro-Nolla et al 2021). One study demonstrates oxybenzone/octinoxate contamination of the eggs of species protected migratory birds existing in bird nature reserves (critical habitat; Molins-Delgado et al 2017). Because oxybenzone and octinoxate bioaccumulate and potentially biomagnify, birds that feed on aquatic and marine species are at risk of exposure, hence a potential risk of impact. Some species of U.S. Endangered Species Act that are potentially at risk include, but are not limited to:

Bird Species

Scientific Name	**Common Name**
Anas oustaleti	Mariana mallard
Anas wyvilliana	Hawaiian (=koloa) Duck
Caloenas nicobarica pelewensis	Palau Nicobar pigeon
Dendrocygna bicolor	Fulvous whistling duck
Halcyon cinnamomina cinnamomina	Guam Micronesian kingfisher
Myiagra freycineti	Guam broadbill
Oceanodroma homochroa	Ashy Storm-petrel
Puffinus auricularis newelli	Newell's Townsend's shearwater
Fulica americana alai	Hawaiian coot
larus atricilla	Laughing gull
Haematopus palliatus	American Oystercatcher
Rynchops niger	Black Skimmer
Sternula antillarum	Least Tern
Charadrius melodus	Piping Plover
Grus americana	Whooping crane
Mycteria americana	Wood stork

Protect species of bivalves at risk in the U.S.:

Bivalves are the quintessential filterfeeders. A number of studies have demonstrated that not only can these filter feeders become highly contaminated by oxybenzone/octinoxate, as well as other UV filters, it can adversely affect their resiliency to climate change, especially increasing effects of ocean acidification (He et al 2019; Lopes et al 2020; Seoane et al 2021). Many of these endangered species live in designated “critical habitats” (https://www.fws.gov/endangered/esa-library/pdf/critical_habitat.pdf). Some species of U.S. Endangered Species Act that are potentially at risk include, but are not limited to:

Clam Species

Scientific Name	**Common Name**
Elliptio chipolaensis	Chipola slabshell
Villosa choctawensis	Choctaw bean
Amblema neislerii	Fat threeridge (mussel)
Pleurobema strodeanum	Fuzzy pigtoe

Medionidus penicillatus	Gulf moccasinshell
Medionidus simpsonianus	Ochlockonee moccasinshell
Elliptio chipolaensis	Chipola slabshell
Hamiota australis	Southern Sandshell
Fusconaia rotulata	Round Ebonyshell
Medionidus walkeri	Suwannee moccasinshell
Cyprogenia stegaria	Fanshell
Potamilus capax	Fat pocketbook
Lampsilis higginsii	Higgins eye pearlymussel
Lampsilis rafinesqueana	Neosho mucket
Epioblasma torulosa rangiana	Northern riffleshell
Epioblasma obliquata obliquata	Purple cat's paw pearlymussel
Quadrula cylindrica cylindrica	Rabbitsfoot
Villosa fabalis	Rayed Bean
Obovaria retusa	Ring pink
Leptodea leptodon	Scaleshell
Plethobasus cyphyus	Sheepnose
Epioblasma triquetra	Snuffbox
Cumberlandia monodonta	Spectaclecase
Quadrula fragosa	Winged maple leaf
Plethobasus cicatricosus	White wartyback pearlymussel
Epioblasma obliquata perobliqua	White cat's paw pearlymussel

Protect species of crustaceans at risk in the U.S.:

Crustacean species can be at risk since sunscreen contamination often pollutes their critical habitats (He et al 2021). Some species of U.S. Endangered Species Act that are potentially at risk include, but are not limited to:

Crustacean Species

Scientific Name	**Common Name**
Stygobromus hayi	Hay's Spring amphipod
Antrolana lira	Madison Cave isopod
Stygobromus (=Stygonectes) pecki	Peck's cave amphipod
Orconectes shoupi	Nashville crayfish
Pacifastacus fortis	Shasta crayfish
Palaemonias alabamae	Alabama cave shrimp
Syncaris pacifica	California freshwater shrimp
Palaemonias ganteri	Kentucky cave shrimp
Thermosphaeroma thermophilus	Socorro isopod
Gammarus acherondytes	Illinois cave amphipod
Spelaeorchestia koloana	Kauai cave amphipod
Lirceus usdagalun	Lee County cave isopod
Palaemonetes cummingi	Squirrel Chimney Cave shrimp
Cambarus zophonastes	Hell Creek Cave crayfish

Cambarus aculabrum	Benton County cave crayfish
Branchinecta conservatio	Conservancy fairy shrimp
Branchinecta longiantenna	Longhorn fairy shrimp
Streptocephalus woottoni	Riverside fairy shrimp
Branchinecta lynchi	Vernal pool fairy shrimp
Lepidurus packardi	Vernal pool tadpole shrimp
Branchinecta sandiegonensis	San Diego fairy shrimp
Gammarus desperatus	Noel's Amphipod
Procaris hawaiana	Anchialine pool Shrimp
Cambarus callainus	Big Sandy crayfish
Vetericaris chaceorum	Anchialine pool shrimp
Gammarus pecos	Pecos amphipod
Gammarus hyalleloides	Diminutive Amphipod
Cambarus veteranus	Guyandotte River crayfish

Protect species of fish at risk in the U.S.:

The toxicological impacts of oxybenzone/octinoxate in fish are described in a later section. Fish larvae are extremely sensitive to the toxic effects of environmentally relevant concentrations of oxybenzone/octinoxate. Furthermore, oxybenzone can impact sex ratio, change sexual phenotype, and alter social behavior in fish.

Some species of U.S. Endangered Species Act that are potentially at risk include, but are not limited to:

Fish Species

Scientific Name	**Common Name**
Chasmistes cujus	Cui-ui
Moapa coriacea	Moapa dace
Etheostoma sellare	Maryland darter
Gambusia gaigei	Big Bend gambusia
Gambusia heterochir	Clear Creek gambusia
Ptychocheilus lucius	Colorado pikeminnow (=squawfish)
Cyprinodon elegans	Comanche Springs pupfish
Cyprinodon diabolis	Devils Hole pupfish
Cyprinodon radiosus	Owens pupfish
Poeciliopsis occidentalis	Gila topminnow (incl. Yaqui)
Oncorhynchus apache	Apache trout
Oncorhynchus gilae	Gila trout
Oncorhynchus clarkii stomias	Greenback Cutthroat trout
Oncorhynchus clarkii seleniris	Paiute cutthroat trout
Etheostoma okaloosae	Okaloosa darter
Gila bicolor ssp. mohavensis	Mohave tui chub
Gila robusta jordani	Pahranagat roundtail chub
Rhinichthys osculus thermalis	Kendall Warm Springs dace
Etheostoma fonticola	Fountain darter
Etheostoma nuchale	Watercress darter
Gambusia nobilis	Pecos gambusia

Cyprinodon nevadensis pectoralis	Warm Springs pupfish
Gasterosteus aculeatus williamsoni	Unarmored threespine stickleback
Oncorhynchus clarkii henshawi	Lahontan cutthroat trout
Plagopterus argentissimus	Woundfin
Percina tanasi	Snail darter
Speoplatyrhinus poulsoni	Alabama cavefish
Erimonax monachus	Spotfin Chub
Percina pantherina	Leopard darter
Etheostoma boschungi	Slackwater darter
Percina rex	Roanoke logperch
Cottus paulus (=pygmaeus)	Pygmy Sculpin
Notropis mekistocholas	Cape Fear shiner
Menidia extensa	Waccamaw silverside
Etheostoma rubrum	Bayou darter
Noturus trautmani	Scioto madtom
Erimystax cahni	Slender chub
Noturus flavipinnis	Yellowfin madtom
Oncorhynchus aguabonita whitei	Little Kern golden trout
Gila elegans	Bonytail
Gambusia georgei	San Marcos gambusia
Cyprinodon bovinus	Leon Springs pupfish
Scaphirhynchus suttkusi	Alabama sturgeon
Gila nigrescens	Chihuahua chub
Gila ditaenia	Sonora chub
Gila seminuda (=robusta)	Virgin River Chub
Etheostoma nianguae	Niangua darter
Noturus baileyi	Smoky madtom
Ictalurus pricei	Yaqui catfish
Amblyopsis rosae	Ozark cavefish
Gila bicolor ssp.	Hutton tui chub
Gila bicolor ssp. snyderi	Owens Tui Chub
Gila purpurea	Yaqui chub
Rhinichthys osculus nevadensis	Ash Meadows speckled dace
Rhinichthys osculus oligoporus	Clover Valley speckled dace
Eremichthys acros	Desert dace
Rhinichthys osculus lethoporus	Independence Valley speckled dace
Etheostoma scotti	Cherokee darter
Noturus placidus	Neosho madtom
Noturus stanauli	Pygmy madtom
Dionda diaboli	Devils River minnow
Tiaroga cobitis	Loach minnow
Cyprinodon nevadensis mionectes	Ash Meadows Amargosa pupfish
Cyprinodon macularius	Desert pupfish
Cyprinella formosa	Beautiful shiner
Notropis cahabae	Cahaba shiner
Notropis albizonatus	Palezone shiner
Notropis simus pecosensis	Pecos bluntnose shiner

Lepidomeda mollispinis pratensis	Big Spring spinedace
Lepidomeda vittata	Little Colorado spinedace
Lepidomeda albivallis	White River spinedace
Crenichthys baileyi grandis	Hiko White River springfish
Crenichthys nevadae	Railroad Valley springfish
Crenichthys baileyi baileyi	White River springfish
Acipenser oxyrinchus	Gulf sturgeon
Chasmistes liorus	June sucker
Deltistes luxatus	Lost River sucker
Xyrauchen texanus	Razorback sucker
Chasmistes brevirostris	Shortnose Sucker
Catostomus warnerensis	Warner sucker
Percina antesella	Amber darter
Percina jenkinsi	Conasauga logperch
Phoxinus cumberlandensis	Blackside dace
Meda fulgida	Spikedace
Etheostoma wapiti	Boulder darter
Percina aurolineata	Goldline darter
Notropis girardi	Arkansas River shiner
Cyprinella caerulea	Blue shiner
Salvelinus confluentus	Bull Trout
Scaphirhynchus albus	Pallid sturgeon
Hypomesus transpacificus	Delta smelt
Eucyclogobius newberryi	Tidewater goby
Etheostoma akatulo	bluemask darter
Etheostoma percnurum	Duskytail darter
Hybognathus amarus	Rio Grande Silvery Minnow
Notropis topeka (=tristis)	Topeka shiner
Catostomus santaanae	Santa Ana sucker
Etheostoma chienense	Relict darter
Acipenser transmontanus	White sturgeon
Etheostoma etowahae	Etowah darter
Etheostoma chermocki	Vermilion darter
Erimonax monachus	Spotfin Chub
Ptychocheilus lucius	Colorado pikeminnow (=squawfish)
Plagopterus argentissimus	Woundfin
Noturus flavipinnis	Yellowfin madtom
Etheostoma trisella	Trispot darter
Catostomus discobolus yarrowi	Zuni bluehead Sucker
Etheostoma phytophilum	Rush Darter
Notropis oxyrhynchus	Sharpnose Shiner
Cottus specus	Grotto Sculpin
Fundulus julisia	Barrens topminnow
Percina aurora	Pearl darter
Noturus flavipinnis	Yellowfin madtom
Etheostoma susanae	Cumberland darter
Noturus baileyi	Smoky madtom

Gila intermedia	Gila chub
Etheostoma percnurum	Duskytail darter
Crystallaria cincotta	diamond Darter
Etheostoma moorei	Yellowcheek Darter
Noturus crypticus	Chucky Madtom
Elassoma alabamae	Spring pygmy sunfish
Notropis buccula	Smalleye Shiner
Etheostoma osburni	Candy darter
Empetrichthys latos	Pahrump poolfish
Etheostoma wapiti	Boulder darter
Erimonax monachus	Spotfin Chub
Chrosomus saylori	Laurel dace
Etheostoma percnurum	Duskytail darter
Noturus stanauli	Pygmy madtom
Erimystax cahni	Slender chub
Erimonax monachus	Spotfin Chub
Noturus flavipinnis	Yellowfin madtom
Scaphirhynchus platorynchus	Shovelnose Sturgeon
Salvelinus confluentus	Bull Trout
Hybognathus amarus	Rio Grande Silvery Minnow
Etheostoma spilotum	Kentucky arrow darter
Salmo salar	Atlantic salmon
Notropis topeka (=tristis)	Topeka shiner

Protect species of coral at risk in the U.S.:

The toxicological impacts of oxybenzone/octinoxate in coral are described in a later section. Coral larvae are extremely sensitive to the toxic effects of environmentally relevant concentrations of oxybenzone/octinoxate. Furthermore, oxybenzone can induce genotoxicity, bleaching, and a reduction in feeding rate.

Some species of U.S. Endangered Species Act that are potentially at risk include:

Orbicella franksi
Acropora palmata
Orbicella annularis
Orbicella faveolate
Dendrogyra cylindrus
Mycetophyllia ferox
Acropora cervicornis

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Impacts and contamination of marine and aquatic invertebrate species

Oxybenzone and octinoxate can induce toxicities in a variety of invertebrate toxicities, from endocrine disruption and reproductive disorders to genotoxicity and altered metabolic conditions. Body burdens oxybenzone/octinoxate occur in species ranging from shrimp and crayfish to sea urchins and bivalves (Han et al 2016; Vidal-Linan et al 2018;. This contamination often occurs as a direct result of point and non-point sources of sewage, and the type of suspended sediment in the system can significantly affect the bioavailability of these two chemicals (Bachelot et al 2012; Yang et al 2021). Even in the realm of "composting" and spreading of oxybenzone/octinoxate on R1 treated sewage water or sewage sludge onto agricultural, golf course, residential field, oxybenzone can induce toxicity in earthworms (Novo et al 2019).

From a community structure perspective, oxybenzone/octinoxate can induce mortality or lethal morbidities for crustacean species at environmentally relevant concentration (Li 2012; Sieratowicz et al 2011; Campos et al 2017; Araujo et al 2020; Bordalo et al 2020). This implies that populations that exist within these plumes will, over time, see a decrease in population density as a result of mortality and reduced individual and reproductive fitness. When this occurs with species that play critical roles within the ecological food web, then high-order predators or consumers are in jeopardy (Boyd et al 2021). Hence, a threat to one species is a threat to the entire community structure (i.e. biodiversity; Campos et al 2019).

It should be noted that a mixture of UV chemicals in the environment can exacerbate toxicity to the organism (Ozaerz et al 2016c).

Benzophenone-3 (OXYBENZONE; oxybenzone; 2-hydroxy-4-methoxybenzophenone; CAS No. 131-57-7) is one of the most widely used of the benzophenones for personal care product formulations and has been used in sunscreen products for over 50 years (Kim and Choi 2014). It is found in aquatic (Rodil et al. 2008; Fent et al. 2010; Balmer et al. 2005; Sanchez-Quiles and Tovar-Sanchez 2015; Daughton and Ternes 1999), marine (Tovar-Sanchez et al. 2013; Sang and Leung 2016; Sánchez Rodríguez et al. 2015; Sharifan et al. 2016; Tsui et al. 2017) and coral reef environments (Bratkovics 2012; Tashiro and Kameda 2013; Downs et al. 2016; Kung et al. 2018; Ku et al. 2020). OXYBENZONE can enter the marine environment directly from swimmers and wastewater discharges (municipal, residential, and vessels), and indirectly from landfill leachates (Rodil et al. 2008; Brausch and Rand 2011). Reef embayments with high visitation (i.e., 100's to 1000's per day) are particularly vulnerable to high concentrations of OXYBENZONE, for example, Trunk Bay, St. John U.S. Virgin Islands (75-95 µg/L Hawksnest, 580-1395 µg/L Trunk Bay, Downs et al. 2016) or Kahalu'u Bay, Hawai'i Island, HI (5-2947 µg/L, Kohala Center https://kohalacenter.org/docs/resources/kbec/Kahaluu_Oxybenzone_Levels_Nov2019.pdf, accessed 7-20-20).

In the Pacific, OXYBENZONE has been measured at beach or snorkeling areas in Hong Kong (0.221-5.4 µg/L, Tsui et al. 2014, 2017), Kenting National Park, Taiwan (0.023-1.23 µg/L, Kung et al. 2018), Okinawa, Japan (nd-1.34 µg/L, Tashiro and Kameda 2013), in nearshore waters of Oahu, Hawaii (Waikiki and Ala Moana, 0.214 to 11.298 µg/L, Woodley 2017 unpublished; >LOD-19.2 µg/L, Downs et al. 2016; 0.0001 – 0.136 µg/L at recreational, municipal and tourist sites, Mitchelmore et al. 2019), and Maui, Hawaii (21 near-shore locations ranging from reference site, La Perouse, 0.00081 to a high of 4.252 µg/L at south of Black Rock, Woodley unpublished data; Table PCP XX). In Florida and the Caribbean, OXYBENZONE concentrations was measured in nearshore waters of Grand Canary Island (3.32 µg/L, Sanchez Rodriguez et al. 2015), St. John U.S. Virgin Islands (Trunk Bay 1943-6073 ng/L, Bargar et al. 2015; Tektite, Red Point, Caneel Bay n.d.), Bonaire (<0.001-1.54 µg/L, Schaap and Slijkerman

2018), St. Croix, U.S. Virgin Islands (Buck Island 0.056-1.35 µg/L, Salt River Bay 0.0001-0.02 µg/L, Rainbow Beach 1.52-2.24 µg/L Woodley 2015, 2019 unpublished), Florida (3.06-15.43 µg/L Miami Beach) and the Florida Keys (3.41-4.47 µg/L Bahia Honda State Park).

OXYBENZONE can convey multiple and different lethal and sub-lethal effects in aquatic taxa as diverse as marine bacteria and viruses (Danovaro and Corinaldesi 2003; Balazs et al. 2016), microalgae (Sieratowicz et al. 2011; Paredes et al. 2014; Thorel et al. 2020), protozoans (Gao et al. 2013), cnideria (Danovaro et al 2008; Downs et al. 2016; He et al. 2019; Fitt et al. 2020), molluscs (Paredes et al 2014; Bachelot et al. 2012; Chaves Lopes et al. 2020), sea urchins (Paredes et al. 2014), crustaceans (Sieratowicz et al. 2011; Paredes et al. 2014; Thorel et al. 2020), and fish (Coronado et al. 2008; Blüthgen et al 2012; Gago-Ferrero et al. 2013, 2015; Soto and Rodríguez-Fuentes 2014; Hannan et al. 2015; Meng et al. 2020). Additionally, OXYBENZONE is known as an endocrine disruptor with non-monotonic dose responses (i.e., low doses have greater effects than higher doses) (Coronado et al. 2008; Krause et al. 2012; Maipas and Nicolopoulou-Stamati 2015; Balazs et al. 2016).

OXYBENZONE is known to bioaccumulate in the soft tissues of many organisms, for example, jellyfish from Palau's UNESCO World Heritage site (0.0025-0.007 µg ww Bell et al. 2017), clams (12.4 ng/g dw Sang and Leung 2016), mussels (nd-10.3 ng/g dw Sang and Leung 2016), squid (2.4-9.04 ng/g ww Peng et al. 2017), crabs (0.94-43.4 ng/g ww Peng et al. 2017), fish (0.68-9.99 ng/g ww Peng et al. 2017), loggerhead sea turtles (<LOD-28.43 µg/mL plasma, Cocci et al. 2020), and raptors (0.31-8.21 ng/g ww Gonzalez-Rubio et al. 2020). In corals, OXYBENZONE was measured in ***Platygyra acuta*****,** ***Porites*** **sp.,** ***Pavona decussata*** from Hong Kong (1.0-38.4 ng/g ww with spatial and seasonal variation with a bioaccumulation factor (BAF) of 2.58-3.01 (Tsui et al. 2017). OXYBENZONE concentrations were similar in ***Porites*** **spp**. (3.2-51.0 ng/g ww Mitchelmore et al. 2019) from Hawaii.

OXYBENZONE toxicity in corals was first described by Danovaro et al. (2008) as causing coral bleaching, however, no toxicity thresholds were reported. Toxicity from exposure to OXYBENZONE and enhanced photo-toxicity have been documented in ***Acropora tenuis*** (Wijgerde et al. 2020), ***Stylophora pistillata*** (Downs et al. 2016; Wijgerde et al. 2020), ***Seriatopora caliendrum*** and ***Pocillopora damicornis*** larvae (He et al. 2019a; Stien et al. 2020) and other cnidarian larvae ***Cassiopea xamachana*** and ***C. frondosa*** (Fit and Hofmann 2020).

OXYBENZONE exposures showed lethal effects in *S. pistillata* larvae (LC50=799 µg/L in darkness; 139 µg/L in light 24 h Downs et al. 2016), while He et al. (2019) observed no mortality in *P. damicornis* (1 mg/L 14 d) and 5 % mortality in *S. caliendrum* larvae (1 mg/L, 7 d). It should be noted the treatments used in He et al. (2019) were not renewed and the residual OXYBENZONE was 2-3% (14 d) of the nominal concentrations.

Sublethal effects of OXYBENZONE exposure included developmental anomalies and bleaching in *S. pistillata* (2.28 µg/L to 22.8 mg/L) and EC50 values of 49 µg/L (light 24 h) and 137 µg/L (darkness 24 h) Downs et al. 2016. For *S. caliendrum* larvae bleaching occurred after 4-5 days (1000 µg/L (He et al. 2019a). Genotoxicity was observed in *S. pistillata* planula (22.8 µg/L to

22.8 mg/L 8 h) with a LOEC 22.8 µg/L (light 8 h) and 228 µg/L (darkness 8 h) (Downs et al. 2016). Larval settlement was reduced to 65 % of control values for *S. caliendrum* (1000 µg/L 14 d He et al. 2019). For *S. caliendrum* nubbins, OXYBENZONE exposure was observed to cause bleaching (LOEC= 500 ug/L) and total polyp retraction (LOEC=10 µg/L 5 d) (He et al. 2019). It should be noted these treatments were not renewed during the 7 d exposure and the residual OXYBENZONE was 1-1.8% (7 d) of the initial nominal concentrations. At low concentration exposures (0.06 µg/L 26 °C), *S. pistillata* and *A. tenuis* nubbins Wijgerde et al. (2020) showed marginal effects at normal temperatures (e.g., 4-5% PSII yield, 16% growth reduction), interestingly the microbiome of *S. pistillata* exposed to OXYBENZONE showed an increase in the family Verrucomicrobiaceae. Negative conditions (recruitment, corals affected by yellow-band disease) in other corals have also been correlated with this bacterial family. At elevated temperatures (0.06 µg/L 33 °C) *S. pistillata* exposures to OXYBENZONE were additive affecting photosynthetic yield and major shifts in the microbiome and decreased the time to mortality observed in *A. tenuis* compared to temperature alone.

Due to animal welfare considerations, and cost and time considerations, alternative toxicity testing using non-animal methods (e.g., *in vitro* cell-based assays and computational modelling) is becoming an industry standard in many countries (e.g., European Union, Israel, India) for regulatory decision-making. To demonstrate the value of primary cell cultures for toxicity testing in coral, calicoblast cells were used to test OXYBENZONE toxicity. Because of the increased sensitivity of coral cells over planulae, correction factors were developed to translate coral cell mortality into an estimate of coral planulae mortality (Downs et al. 2016). Cell viability assays were used to determine median lethal concentrations (LC50s) of OXYBENZONE for seven different coral species (***S. pistillata*** (42 µg/L)**,** ***Montastraea cavernosa*** (52 µg/L)**,** ***Orbicella annularis*** (74 µg/L)**,** ***Porites astreoides*** (340 µg/L), ***Acropora cervicornis*** (9 µg/L)**,** ***P. damicornis*** (8 µg/L)**,** ***Porites divaricata*** (36 µg/L)), exposed for 4 h in the light. LC20s (4 h, light) for the same species ranged from 0.062 to 8 µg/L (Downs et al. 2016; Table XX). Using cell-based assays reduced the exposure time, increased the throughput, while reducing the amount of coral biomass that would otherwise be required if coral nubbins were used as well as labor costs.

Ecological risk assessments (i.e., hazard quotients) were calculated for several of the study locations for coral and other receptor species. He et al. determined OXYBENZONE posed a medium-high risk to coral health. Various receptor species (non-coral) exposed to OXYBENZONE in aquatic environments (Kim and Choi 2014; Sang and Leung 2016; Sánchez Rodríguez et al. 2015) collectively indicating that OXYBENZONE are highly suspected of having an adverse effect on the marine aquatic environment.

Octinoxate (EHMC, ethylhexyl methoxycinnamate, Uvinul MC80, CAS No. 5466-77-3) is used for UVB protection (290-320 nm) and in sunscreen products up to 7.5%. Environmental levels have been reported in beach waters of Spain (35.7-52.5 ng/L Paredes et al. 2014), Hong Kong surface waters (89-4043 µg/L Tsui et al. 2014), Japanese beaches (11-1080 ng/L, Sankoda et al. 2015), Canary Islands (756.4 ng/L Sanchez Rodriguez 2015), shoreline of Trunk Bay US Virgin Islands (avg. 41 ng/L Bargar et al. 2015), coastal South Carolina (30-264 ng/L Bratkovics and Sapozhnikova 2011). EHMC was measured in fish (n.d.- 8.8 ng/g dw), clams (24.6-33.1 ng/g dw), and mussels (n.d. – 51.3 ng/g dw) from mariculture farms along the coast of Hong Kong

(Sang and Leung 2016). Although in Europe, maximum concentrations of EHMC were much higher, e.g., mussels reached 7112 ng/g (dw) (Groz et al. 2014) and in France ranged from 3-256 ng/g (dw) (Bachelot et al. 2012).

Toxicity of octinoxate was tested in two coral species, ***Seriatopora caliendrum*** and ***Pocillopora damicornis*** alone and also exposed to dilutions of a 'wash-off' of a sunscreen product (7% octinoxate, 3.6% OC) (He et al. 2019). In the single octinoxate tests (7 d), partial mortality (1000 µg/L, 33.3%) or bleaching (1000 µg/L, 83.3%) occurred only in *S. caliendrum* fragments. Sunscreen product (5% of sunscreen 'wash-off' 422.34 µg/L octinoxate and 33.50 µg/L octocrylene) exposures were significantly more toxic than individual chemical exposures, high mortality occurred in both species within 24 h (*S. caliendrum* 66.7-83.3%; *P. damicornis* 33.3-50%) >5% sunscreen product wash-off caused 100% mortality. Tissue levels had 10-fold greater concentrations of UV filters from exposure to sunscreen product than in single exposures. Total polyp retraction in both species occurred at lower concentrations (LOEC= 100 (EHMC) µg/L : 5 (OC) µg/L). Exposure to octinoxate caused total retraction of *S. caliendrum* polyps (10-1000 µg/L). EHMC toxicity was evaluated in organisms from multiple trophic levels, algae (*Isochrysis galbana* EC50= 74.73 µg/L), mussels (*Mytilus galloprovincialis,* 3118.19 µg/L), sea urchin larvae (*Paracentrotus lividus*, EC50=284 µg/L), shrimp (*Siriella armata*, EC50=199.43 µg/L) (Paredes et al. (2014) and *Daphnia magna* (EC50=0.29 mg/L (Fent et al. 2010).

Modes of Toxicity:

Cytokine, pheromone and endocrine disruption. Oxybenzone can alter the expression of a number of chaperonin and regulatory genes in invertebrate models, resulting in reduced fitness (Ozaez et al 2013, 2014, 2016a, 2016b; Martin-Folgar et al 2017).

Reproduction and multi-generational effects. The benthic aquatic insect model, Chironomus riparius, when exposed to oxybenzone exhibited reproductive degradation, inhibition of egg hatching success (Campos et al 2019). Furthermore, oxybenzone exposure caused a multi-generational response, increasing the susceptibility of the F1 offspring to the toxic effects of oxybenzone (Campos et al 2019).

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Impacts and contamination of marine and freshwater fish species

Oxybenzone has been documented to induce a number of acute and temporally delayed pathologies in fish after an acute exposure. It is important to note that oxybenzone/octinoxate are considered pseudo-persistent pollutants. Their contamination from a source is usually refreshed daily. For example, in the event of a popular swimming beach, sunscreen contamination can occur daily from 8 am to 5 pm. For point-sources of sewage, contamination can occur constantly, its concentration changing by the use-rate of the waste-water treatment system. Contamination in fisheries species can pose a threat to public health; bioaccumulation of oxybenzone and octinoxate in subsistence species of fish can pose a threat to public health (Gago-Ferrero et al 2015; Ziarrusta et al 2018).

Modes of Toxicity:

It should be noted that natural sunlight can exacerbate the toxicity of oxybenzone has to an organism. Most ecotoxicological studies are done under laboratory light conditions (20 umoles photons s-1 m-2) when noon light incidence outside on a sunny day can be around 2,000 umoles photons s-1 m-2). Studies on the interaction of light and chemical toxicity are just beginning to be explored (Downs et al. 2016; Nataraj et al 2021; Zhang et al 2021).

Lesion manifestation on gills and liver as a result of an acute exposure. Oxybenzone exposure can cause lesions to form on the gills and livers of fish under environmententally relevant exposure (dos Santos Almeida et al 2021).

Estrogenic and anti-androgenic disruptor. Oxybenzone exposure is an establish endocrine disruptor in fish. It can cause a number of radical changes, from inducing vitellogenin in adult male and juvenile fish to detrimentally altering social mating behaviors (see references from this section). From a generational perspective, oxybenzone can also alter secondary sex ratios in fish. "Skewing of the sex ratio is a marker of an endocrine-mediated mechanism as well as a marker of adversity, and therefore the conclusion of the present study is that OXYBENZONE (oxybenzone) is an endocrine-disrupting chemical in accordance with the World Health Organization's definition" (Kinnberg et al 2015).

In vitro hormonal-response assays indicate that octinoxate can have multiple and distinct activities anti-androgenicity was coupled with anti-estrogenic while androgenic activity was distinct (Kunz and Fent 2006).

Genotoxicity. Oxybenzone exhibited genotoxicity in a fish model at environmentally relevant exposure concentrations (Zhang et al 2017; dos Santos Almeida et al 2019).

Developmental Toxicity. Both oxybenzone and octinoxate induce developmental toxicities in fish at environmentally relevant concentrations (Nataraj et al 2020; Tao et al 2020; Zhange et al 2021). Photoproducts of oxtinoxate and chlorinated-products of oxybenzone exhibit increased toxicity to early stages of fish development as compared to the parent products.

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Impacts and contamination of plant and algae species

Oxybenzone and octinoxate can be acutely toxic to both algal and plant taxons (Sieratowicz et al 2011' Du et al 2017; Esperanza et al 2019; Mao et al 2018; Teoh et al 2019; Leet et al 2020). Oxybenzone was demonstrated to have adverse effect on algal replication (growth) and chlorophyl anabolism as low as 10 parts per trillion (Mao et al 2017). Oxybenzone and octinoxate can directly impact the light reactions of photosynthesis, the photosynthetic electron transport chain (Zhong et al 2019; Zhong et al 2020). Oxybenzone has been demonstrated to adverse impact the Calvin cycle of photosynthesis (Zhong et al 2019b).

Oxybenzone, and to a lesser degree, octinoxate, pose significant threats to the community structure of almost any freshwater and marine ecosystem; it threatens primary production. This ecological threat ranges from pelagic phytoplankton biodiversity and population density, to sea grass bead of the southeastern U.S. coastal region, and the kelp forests that range from Washington to California. The number of species that could be effected by damaging the primary producers of these ecosystems is vast. Ranging from manatees and green sea turtles that directly subsist on macroalgae and seagrass to corals.

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Environmental Synergisms increasing the toxicity of sunscreens

Sunscreen pollution, especially that of oxybenzone, can synergistically interact with other global and local stressors, thereby reducing the resiliency of marine ecosystems to the impacts of climate change (Laffoley et al. 2019). For some invertebrates, especially corals, oxybenzone exposure can exacerbate the pathologies induced by heat stress (Muñiz-González and Martínez-Guitarte 2020; Wijgerde et al. 2020). In shellfish, oxybenzone exposure can intensify the manifestations of ocean acidification, potentially altering shell formation (Chaves Lopes et al. 2020). Marine microplastic debris is now considered a global scourge, and the coupling of sunscreen pollution with micro/nano-plastics pollution enhances the toxicity of both stressors (Beiras et al. 2018; O'Donovan et al 2020; Achar et al. 2021; Na et al 2021). Nitrogen and phosphorous pollution are often combined with sunscreen chemicals (e.g., oxybenzone, avobenzone, octocrylene) in sewage effluent, posing a synergistic threat to induce coral bleaching (Wiedenmann et al. 2013; Burkepile et al. 2020; Donovan et al. 2020). Coral reefs and marine ecosystems that are afflicted with "a thousand small insults" can become highly compromised and lose their ability to withstand global-level stressors (Harbone et al. 2017; Richmond et al. 2018). To increase the resiliency of our reefs to both global and regional stressors, we need to quickly and effectively mitigate these localized stressors and provide a measure of relief that in some circumstances may mean the difference between extinctions or persistence of these fragile ecosystems.

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Genotoxicity

Both oxybenzone and octinoxate exhibit genotoxicity in their native structure, but especially for photo-modified and chlorinated products (Zhang et al. 2016).

Oxybenzone:

Oxybenzone has been demonstrated to be genotoxic to both plant/algae species, as well as a variety of species within the Kingdom Animalia (Tovar-Sanchez et al 2013; dos Santos Almeida et al 2019). Oxybenzone induced the SOS response in S. Typhuumurium SOS/umuC genotoxicity assay under both without metabolism to an S9 fraction as well as to metabolism of the Aroclor 1254 induced male rate liver pos-mitochondial S9 fraction (Zhao et al 2013; Kotnik et al 2016). Oxybenzone induced mechanisms that initiate genes related to carcinogenesis are often assessed using the umu-test (Nakajima et al 2006). NTP Technical Report on Toxicity studies demonstrated that oxybenzone is weakly mutagenic in Salmonella (French 1992). Like octinoxate, the mode of genotoxicity is photo-dependent, and exposure may induce other forms of photo-associated phototoxicity, such as oxidative damage (Majhi et al 2020).

A number of ecotoxicological studies, ranging from coral and fish to plants, demonstrate genotoxicity of oxybenzone (Downs et al. 2016; dos Santos Almeida et al 2019)

Octinoxate:

In the case of trans-EHMC, significant genotoxicity was observed (Bonin et al 1982; Sharma et al Shimoi et al 1988; 2017), as well as chlorinated-octinoxate products (Nakajim et al 2009; Manasfi et al 2019). It has been demonstrated to help prevent cyclobutene pyrimidine dimer formation under a UV environment, but it does not prevent the formation of oxidative DNA-damage under the same conditions (Duale et al 2010).

According to Nexasova et al (2016), "the genotoxic effects of the isolated cis-EHMC isomer and the nonirradiated trans-EHMC were subsequently measured using two bioassays (SOS chromotest and UmuC test). In the case of trans-EHMC, significant genotoxicity was observed using both bioassays at the highest concentrations (0.5 - 4 mg mL21).In the case of cis-EHMC, significant genotoxicity was only detected using the UmuC test at concentrations of 0.25 - 1 mg mL21. Based on these results, the NOEC was calculated for both cis- and trans-EHMC, 0.038 and 0.064 mg mL21, respectively. Risk assessment of dermal, oral and inhalation exposure to PCPs containing EHMC was carried out for a female population using probabilistic simulation and by using Quantitative in vitro to in vivo extrapolation (QIVIVE). The risk of cis-EHMC was found to be 1.7 times greater than trans-EHMC. In the case of cis-EHMC, a hazard index of 1 was exceeded in the 92nd percentile. Based on the observed differences between the isomers, EHMC application in PCPs requires detailed reassessment."

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