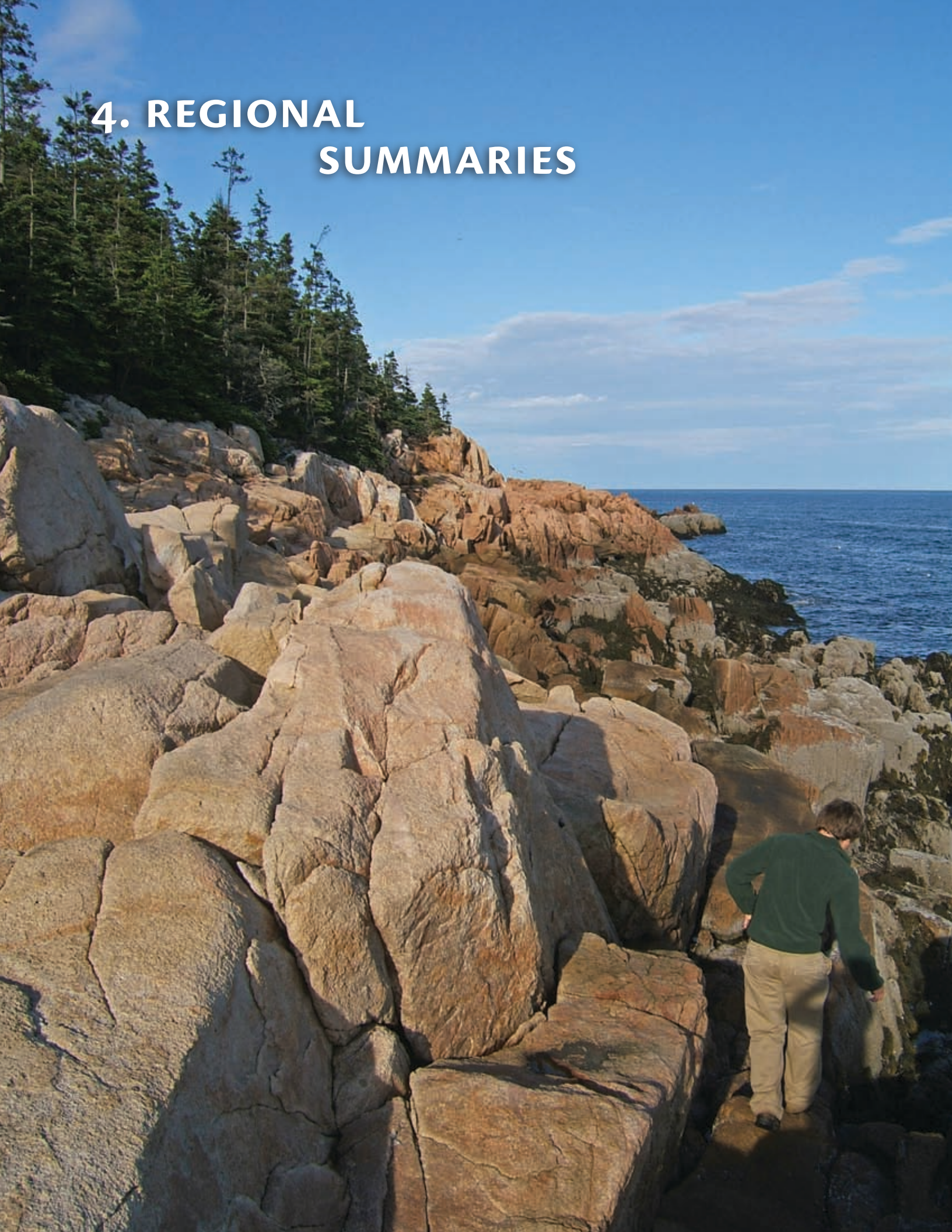
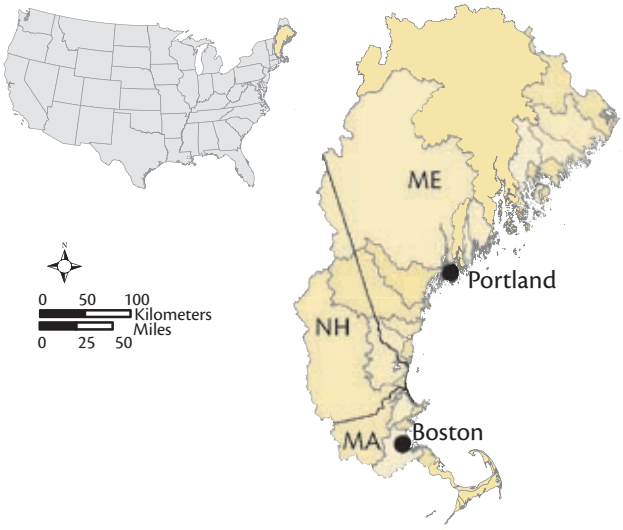
4. REGIONAL SUMMARIES



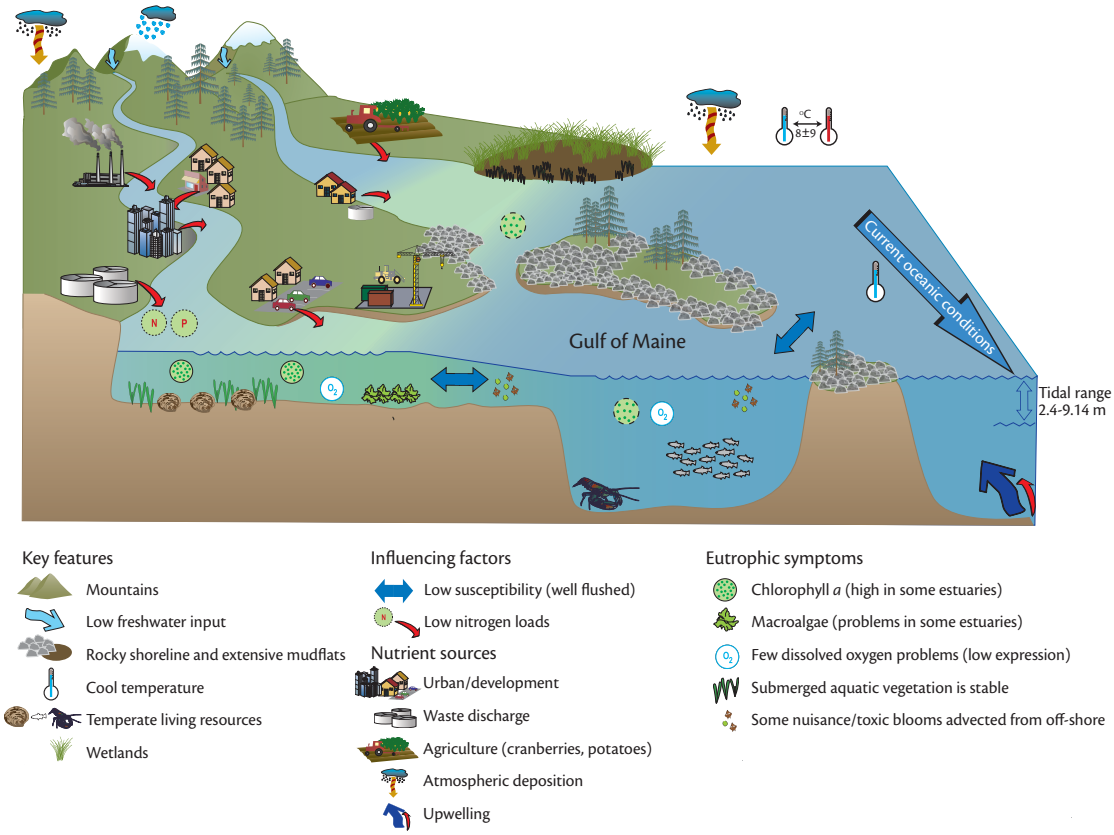
NORTH ATLANTIC REGION

- Factors influencing eutrophication were low for all assessed systems (9 out of 20 in the region).
- The least impacted region—no systems had a high overall eutrophic condition rating.
- Some systems had worsening chlorophyll *a* and macroalgae.



The North Atlantic region includes 20 estuarine systems, encompassing roughly 5,300 km² of water surface area. In the north, the coastal shoreline consists mainly of drowned river valleys characterized by numerous small embayments, rocky shorelines, wave-cut cliffs, and large, rocky islands (Figure 4.1). The southern part consists of drowned river valleys characterized by cobble, gravel, and sand beaches, and extensive tidal marshes. Average depth ranges from less than one meter to more than 45 meters. The large tidal ranges, about two to five meters, result in a high degree of tidal flushing, often combined with low freshwater input. The high tidal range and circulation patterns in the Gulf of Maine result in offshore waters contributing nutrients and toxic algal blooms to some of the northern systems. The North Atlantic climate is cooler than the other regions, with an average annual air temperature of 8°C, 156 frost days, and 1.2 m precipitation per year. The average regional watershed population density is 65 people km^{-2} and major population centers are Portland and Boston.

Figure 4.1. Conceptual diagram of North Atlantic key features, major nutrient sources, and resulting symptoms.



Influencing factors

- All systems for which data were available exhibited low influencing factors.

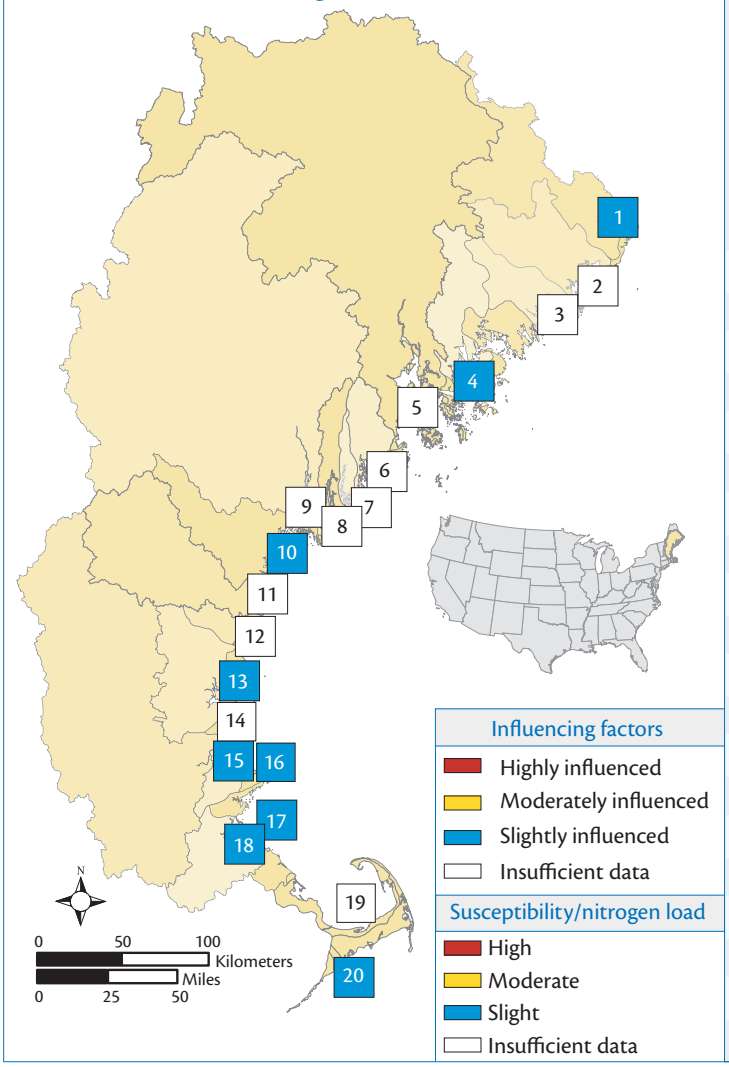
Nitrogen loads, represented as the ratio of watershed to oceanic inputs, are rated as high in only one North Atlantic system and low in eight others (Figure 4.2). Overall, this region has low human influence due to low freshwater inflow and generally sparse population. Dominant sources of nutrients in this region are wastewater treatment, urban runoff, septic tanks, and atmospheric deposition. For northern systems, offshore coastal waters may be a more significant source of nutrients than land based sources. Susceptibility is predominantly low, resulting from high tidal flushing and moderate to good dilution capabilities of systems. A particularly notable reduction in influencing factors since the 1999 assessment occurred in Boston Harbor, due to the diversion of wastewater treatment plant discharge.

Caroline Wicks, EcoCheck (NOAA/University of Maryland Center for Env. Science)

Rocky shorelines are common along the North Atlantic coast.

Figure 4.2. Map of influencing factors ratings, ratings of components of influencing factors, and 1999 ratings in the North Atlantic region.

Influencing factors: 2004



Influencing factors: comparisons

Estuary	2004 Influencing factors	2004 Susceptibility	2004 Nitrogen load	1999 Influencing factors
1. St. Croix R./Cobscook Bay	Slightly influenced	Slightly influenced	Slightly influenced	Slightly influenced
2. Englishman Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
3. Narraguagus Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
4. Blue Hill Bay	Slightly influenced	Slightly influenced	Slightly influenced	Slightly influenced
5. Penobscot Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
6. Muscongus Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
7. Damariscotta River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
8. Sheepscot Bay	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
9. Kennebec/Androscoggin R.	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
10. Casco Bay	Slightly influenced	Slightly influenced	Slightly influenced	Slightly influenced
11. Saco Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
12. Wells Bay	Insufficient data	Slightly influenced	Insufficient data	Insufficient data
13. Great Bay	Slightly influenced	Moderately influenced	Slightly influenced	Slightly influenced
14. Hampton Harbor Estuary	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
15. Merrimack River	Slightly influenced	Slightly influenced	Highly influenced	Slightly influenced
16. Plum Island Sound	Slightly influenced	Moderately influenced	Slightly influenced	Highly influenced
17. Massachusetts Bay	Slightly influenced	Slightly influenced	Slightly influenced	Moderately influenced
18. Boston Harbor	Slightly influenced	Moderately influenced	Slightly influenced	Highly influenced
19. Cape Cod Bay	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
20. Waquoit Bay	Slightly influenced	Slightly influenced	Slightly influenced	Insufficient data

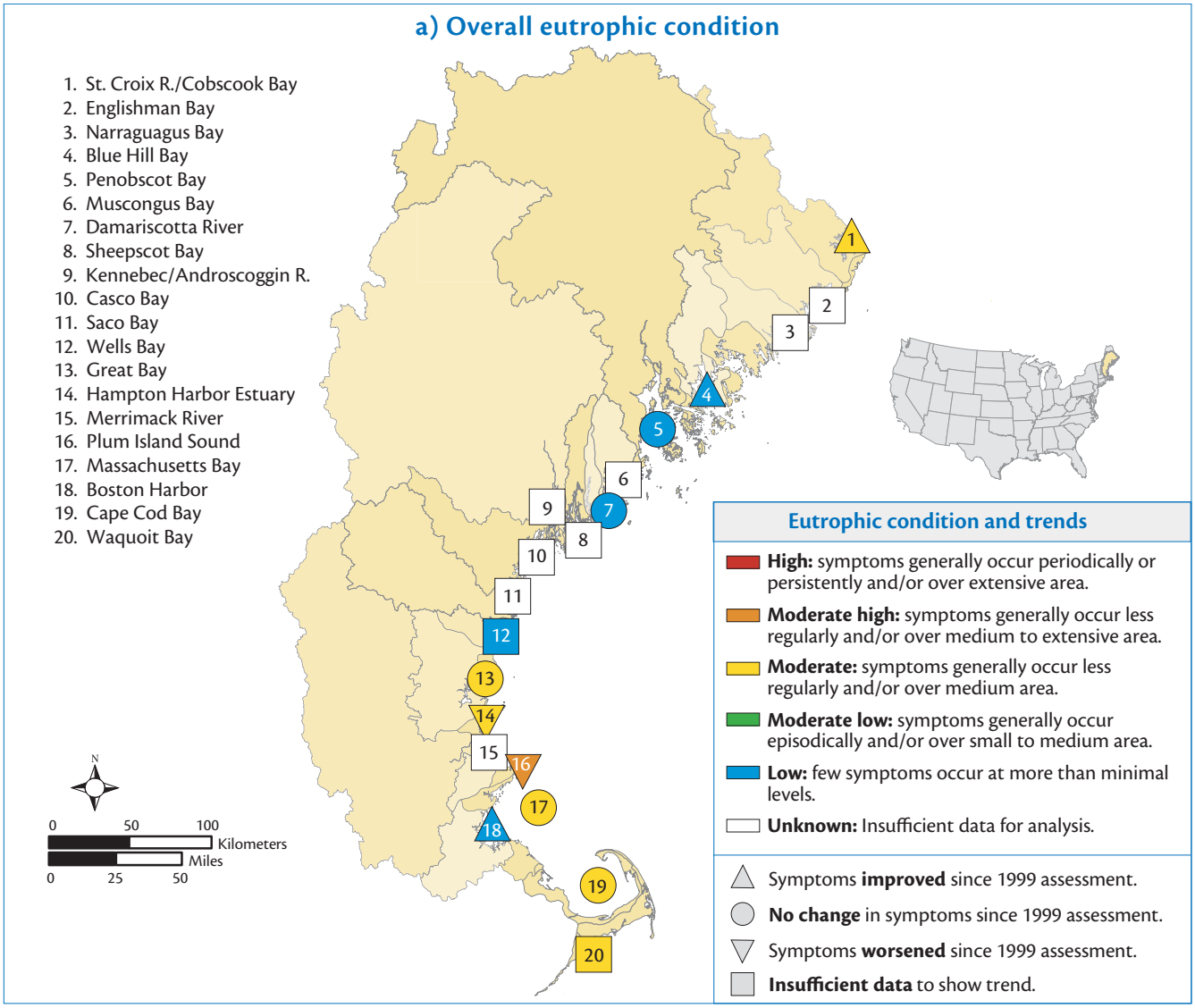
Overall eutrophic condition

- This is the least impacted region; no North Atlantic systems had high overall eutrophic condition (OEC).
- The majority of systems had a moderate or low OEC.
- There was some cause for concern for chlorophyll *a* and macroalgae.
- Toxic offshore blooms which leave cysts (potential future blooms) were an emerging issue.

The North Atlantic region is the least eutrophic region in the nation, with the majority of systems having moderate or low overall eutrophic condition (Figure 4.3a-b). Furthermore, no estuaries in this region recorded high overall eutrophic condition—a unique feature, as all other regions have at least one estuary with a high rating. One system was classified as having moderate high eutrophic conditions, with chlorophyll *a* and nuisance/toxic blooms as the major contributing symptoms.

One notable characteristic in systems of this region is the annual occurrence of nuisance/toxic blooms, which cause shellfish bed closures. However, for systems such as Massachusetts, Cape Cod, Saco, and Casco Bays, these blooms originate offshore and are advected into the systems. For this reason, the nuisance/toxic bloom rating for these systems has been adjusted to low since the blooms do not originate within the system. An emerging issue is the possibility that these blooms, mostly of *Alexandrium* spp., may eventually originate within estuaries, due to cysts that have settled in the estuarine sediments.

Figure 4.3. (a) Map of overall eutrophic condition (OEC) and (b) the combination of individual eutrophic symptoms which constitute OEC ratings in the North Atlantic region.



The overall confidence in the assessments for this region is low due to almost a third of the systems (eight) having inadequate data for assessment. Where data were available, confidence is moderate to high.

Eutrophic symptom expressions

Systems with moderate or moderate high overall eutrophic condition were characterized by having one high symptom expression, which in this region was most often chlorophyll *a* and macroalgae.

While most estuaries had one high symptom expression, the majority of symptom expressions were low. For the primary symptoms, chlorophyll *a* was expressed as low in seven of the eleven estuaries for which the symptom was reported. Similarly, macroalgae symptom expressions were low in five of the ten reported estuaries. For the secondary symptoms, dissolved oxygen problems were low in all twelve systems, and losses of submerged aquatic vegetation (SAV) were low in all eight systems for which there were data.

Changes in eutrophic condition since the 1990s

Overall eutrophic conditions worsened in two systems, improved in three systems, and did not change in five when compared to the 1999 report (Figure 4.3a-b). Chlorophyll *a* changed in more systems than any of the other symptoms, showing improvements in four systems and worsening conditions in three systems. Of the data available, dissolved oxygen displayed the least amount of change.

Of particular interest is the improvement of eutrophic condition in Boston Harbor, which had moderate high eutrophic status in the 1990s, but currently has a rating of low. All symptom improvements were attributed to sewage treatment upgrades and the move of the wastewater outfall from the harbor into Massachusetts Bay.

b) Overall eutrophic condition & eutrophic symptoms

Estuary	Overall eutrophic condition	Overall confidence expression	Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/toxic blooms	SAV
1. St. Croix R./Cobscook Bay	Moderate	***	Low	High	Low	Moderate	Low
2. Englishman Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
3. Narraguagus Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
4. Blue Hill Bay	Moderate high	***	Moderate high	Low	Low	Low	Low
5. Penobscot Bay	Low	*	Low	Low	Low	Low	Insufficient data
6. Muscongus Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
7. Damariscotta River	Low	*	Insufficient data	Low	Insufficient data	Low	Insufficient data
8. Sheepscot Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
9. Kennebec/Androscoggin R.	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
10. Casco Bay	Insufficient data	*	Insufficient data	Insufficient data	Low	Moderate high	Moderate high
11. Saco Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Low	Insufficient data
12. Wells Bay	Moderate	**	Moderate	Moderate	Moderate	Moderate	Moderate
13. Great Bay	Moderate	***	Moderate high	Moderate	Low	Low	Low
14. Hampton Harbor Estuary	Moderate	**	Moderate high	Moderate	Low	Low	Low
15. Merrimack River	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
16. Plum Island Sound	Moderate high	*	Moderate	Insufficient data	Low	Moderate	Insufficient data
17. Massachusetts Bay	Moderate	*	Moderate	Insufficient data	Low	Moderate high	Insufficient data
18. Boston Harbor	Moderate high	***	Moderate high	Moderate high	Moderate high	Low	Low
19. Cape Cod Bay	Moderate	*	Moderate	Moderate	Low	Low	Insufficient data
20. Waquoit Bay	Moderate	***	Moderate	High	Moderate	Moderate	Moderate

Eutrophic condition in 2004
- High
- Moderate high
- Moderate
- Moderate low
- Low
- Insufficient data

Overall confidence expression in 2004
- *** High
- ** Moderate
- * Low

Change in eutrophic condition since 1999 assessment
- Improved
- No change
- Worsened
- Insufficient data

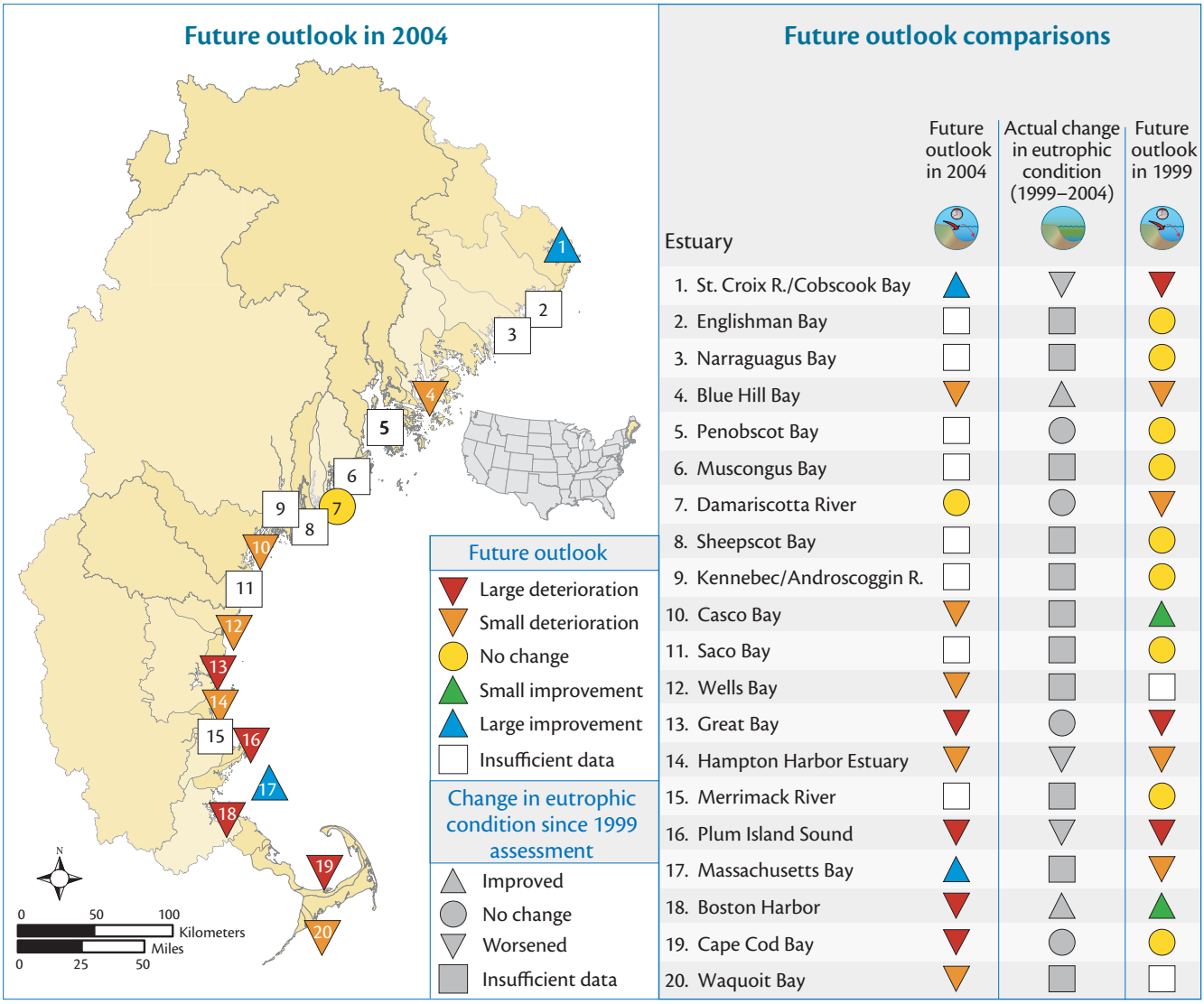
Future outlook

- There was a bleak outlook for future conditions; most systems for which an evaluation was made were expected to worsen in the future.
- The future outlook has not changed from the early 1990s.

The overall future outlook for the North Atlantic region predicts worsening conditions. Eutrophication symptoms were predicted to worsen in nine of the assessed systems and to improve in only two (Figure 4.4). For the nine systems expected to worsen, nutrient loads are anticipated to increase due to wastewater treatment, urban runoff, onsite septic tanks, combined sewer overflow (Cape Cod Bay only), atmospheric deposition, increasing impervious surfaces, and fertilizer use. For all systems, an increase in coastal population (affecting land use distribution and subsequent nutrient loads) is likely to augment nutrient loads from all of these sources.

Though it is premature to make conclusions about the accuracy of the 1999 assessment's future outlook, in six out of nine systems (for which comparison could be made), actual changes trended in the same direction as predicted. Worsening conditions due to increased nutrient loads are expected in Boston Harbor, Great Bay, Plum Island Sound, and Cape Cod Bay (Figure 4.4). Conversely, loads to St. Croix River/Cobscook Bay and Massachusetts Bay are expected to decrease due to improvements in onsite septic tanks, storm water management, restoration of eroding stream beds, and a reduction in salmon aquaculture. These changes are expected to occur by 2020.

Figure 4.4. Future outlook in 2004 and comparison with 1999 future outlook.



National Oceanic and Atmospheric Administration

Fishing boats tied up at the Portland Marine Trade Center in Portland, Maine. Monitoring use impairments is important to understanding how eutrophication influences commercial and recreational fishing.

Assessment of Estuarine Trophic Status (ASSETS)

There were seven systems for which an ASSETS rating (combination of influencing factors, overall eutrophic condition, and future outlook) could be made. Two systems were rated as good (Boston Harbor, Blue Hill Bay), four were rated as moderate (St. Croix River/Cobscook Bay, Great Bay, Massachusetts Bay, and Waquoit Bay), and one as poor (Plum Island Sound).

Impaired uses

- Three systems had impaired living resources.
- Causes of impairments were reported as river input, wastewater treatment, combined sewer outflow, urban runoff, fertilizer, and onsite septics.
- Six systems had human use impairments (primarily shellfish harvesting, and recreational and commercial fishing).
- There were no clear correlations between overall eutrophic condition and impacts to living resources.

Living resources were identified as being considerably impaired in only one estuary (Waquoit Bay), a result of onsite septic tanks and fertilizer. Two additional systems reported moderate to slight impacts (Boston Harbor and Great Bay) due to river inputs, wastewater treatment, combined sewer overflow (combination of WWTP and sewer overflow), and urban runoff. However, this information was available for only five of the twenty systems.

Use impairments were reported for six systems (Damariscotta River, Great Bay, Hampton Harbor, Boston Harbor, Cape Cod Bay, Waquoit Bay) with the most frequently noted impairment being shellfish harvesting. Other impacts include recreational and commercial fishing and fish consumption, aesthetics, and swimming.

There does not seem to be a clear correlation between the level of overall eutrophic condition and impacts to living resources. For instance, Waquoit Bay (moderate OEC) had considerably impacted living resources while St. Croix River/Cobscook Bay, also with moderate overall eutrophic condition, had no impacts. This is likely due to the quantitative nature of the OEC rating and the qualitative nature of use impairment reporting (i.e., these impairments occurred during the time period, but degree of impairment was not noted). The difference could also reflect the subtlety that nuisance/toxic blooms, which may be advected from offshore, are in many North Atlantic systems not considered a result of eutrophication. Therefore a comparison between the two is difficult. All systems with some level of eutrophic condition reported impairments.

Potential management concerns

The nutrient sources noted as the causes of impairments to living resources were combined sewer overflow, wastewater treatment, onsite septic tanks, urban runoff, fertilizer use, and river inputs. Atmospheric inputs were also noted as a cause for changes in load during the past decade. All of these warrant management attention given that they are also reported as potential causes of future nutrient increases and worsening conditions.

Data gaps and research needs

Monitoring

Approximately one third of the systems included in this region had insufficient data for assessment. It is recommended that there be an emphasis on better regional monitoring of all indicators, submerged aquatic vegetation and macroalgae in particular. This includes improved assessments of nutrient inputs from rivers, groundwater, and aquaculture so that the causes of observed problems can be identified and addressed. A monitoring program should provide a unified approach for sampling and analyzing indicators (i.e., macroalgae) in all systems, including annual sampling with more intensive sampling during seasons that are problematic (i.e., summer).

Research

A better understanding of circulation dynamics is needed in these systems. Also, improved estimates of population growth and land use impacts and distribution are needed in order to make accurate projections about future conditions. For systems with seasonal population changes, more research is needed in order to assess the effects of winter-summer population changes on eutrophic conditions in estuaries. Finally, improved macroalgal monitoring and assessment techniques are recommended.

Kate Boicourt, EcoCheck (NOAA/University of Maryland Center for Env. Science)

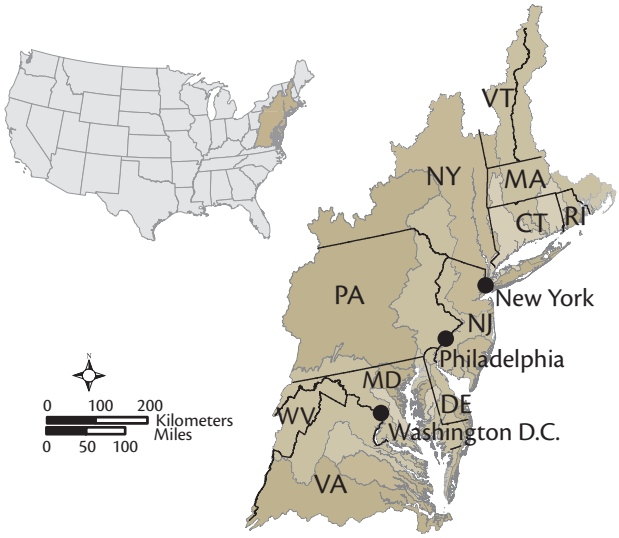
A volunteer taking water samples to monitor for toxic bloom species of algae in Penobscot Bay, Maine.

Management

The survey should be adjusted to accurately reflect relative conditions in different systems. Participants at the NEEA workshop noted that the assessment method should be improved so that the relative conditions among systems in this region would be more accurately reflected. For instance, they argued that despite the improvements to Boston Harbor, the eutrophic conditions of Great Bay are still better than those of Boston Harbor, contrary to the results of the survey. It is important that the relative ratings accurately reflect conditions since this will impact the prioritization of systems needing management and thus the application of scarce resources to improve conditions. For the most part the systems in this region are not presently highly impacted.

MID–ATLANTIC REGION

- Factors influencing eutrophication were high for the majority of systems.
- The most impacted of all the regions—majority of systems had a moderate high or high overall eutrophic condition rating.
- High chlorophyll *a* symptom expression was observed in the majority of systems.



The mid-Atlantic region includes 22 estuaries, encompassing more than 20,300 km² of water surface area. This is a temperate region with an average annual air temperature of 12°C, 101 frost days, and 1.1 m precipitation per year. These systems are generally of two types: drowned river valleys and coastal lagoons. The drowned river valleys are characterized by deep channels, relatively high exchange with the ocean, and moderate to high freshwater inflow (Figure 4.5a). Average depths for all systems in the region range from 0.65–19.5 m with drowned river valley systems having an average of 4.7 m. Tidal range is on average 0.86 m and tidal flushing is dominant in the northern systems. These watersheds encompass major population centers including Providence, RI, Hartford, CT, New York City, NY, Philadelphia, PA, Baltimore, MD, Washington, DC, and Richmond, VA. The regional average population density is 156 people per km² of catchment, with significant acreage also dedicated to agricultural activity.

Coastal lagoons are shallow (2 m or less), and are enclosed by barrier lagoons which limit oceanic exchange (Figure 4.5b). Typically, freshwater inflow is very low, and the average lagoonal tidal range is small (0.49 m) compared to the regional range (0.24-1.85 m). These characteristics result in longer flushing times than those of the drowned river valley estuaries. Coastal lagoon watersheds also are subject to significant agricultural activity and dynamic population, due to summertime tourism of beaches and towns along the Atlantic coastline.

National Oceanic and Atmospheric Administration

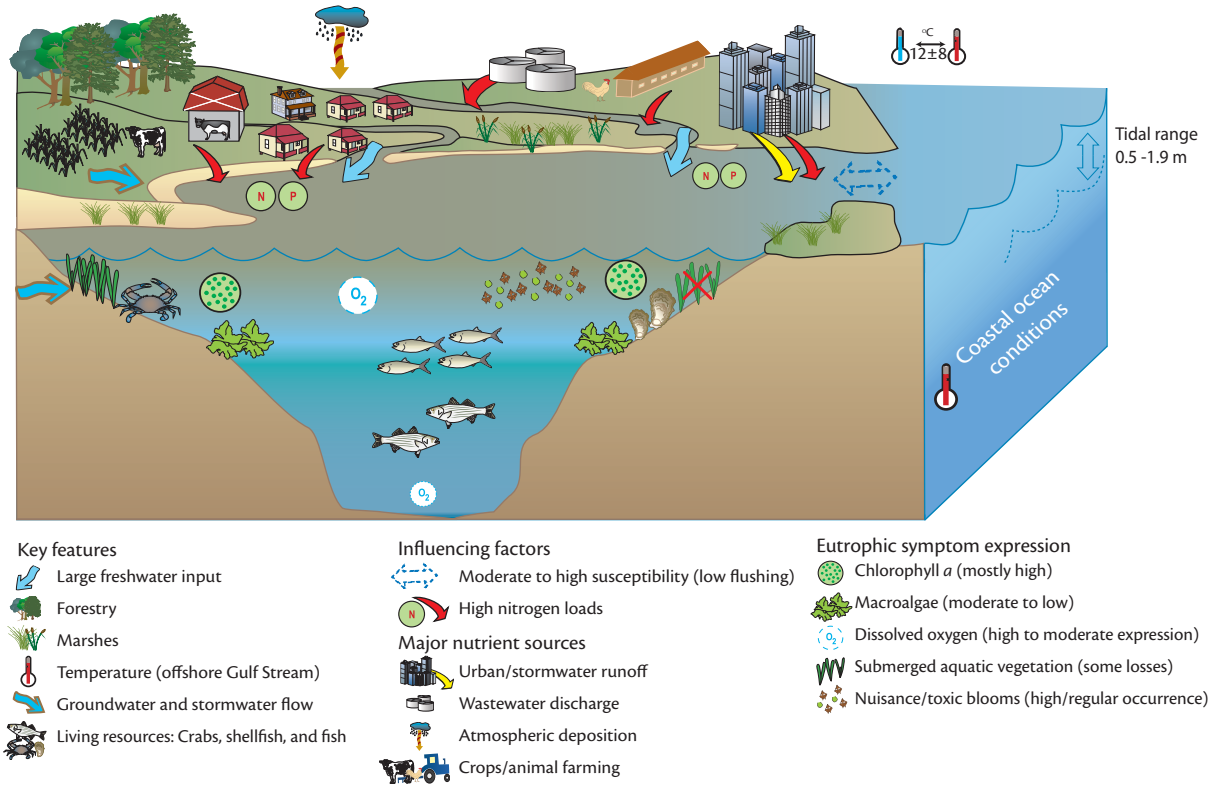
Narragansett Bay is an estuary in Rhode Island typical of the drowned river valleys in the mid-Atlantic region.

Jane Thomas, University of Maryland Center for Environmental Science

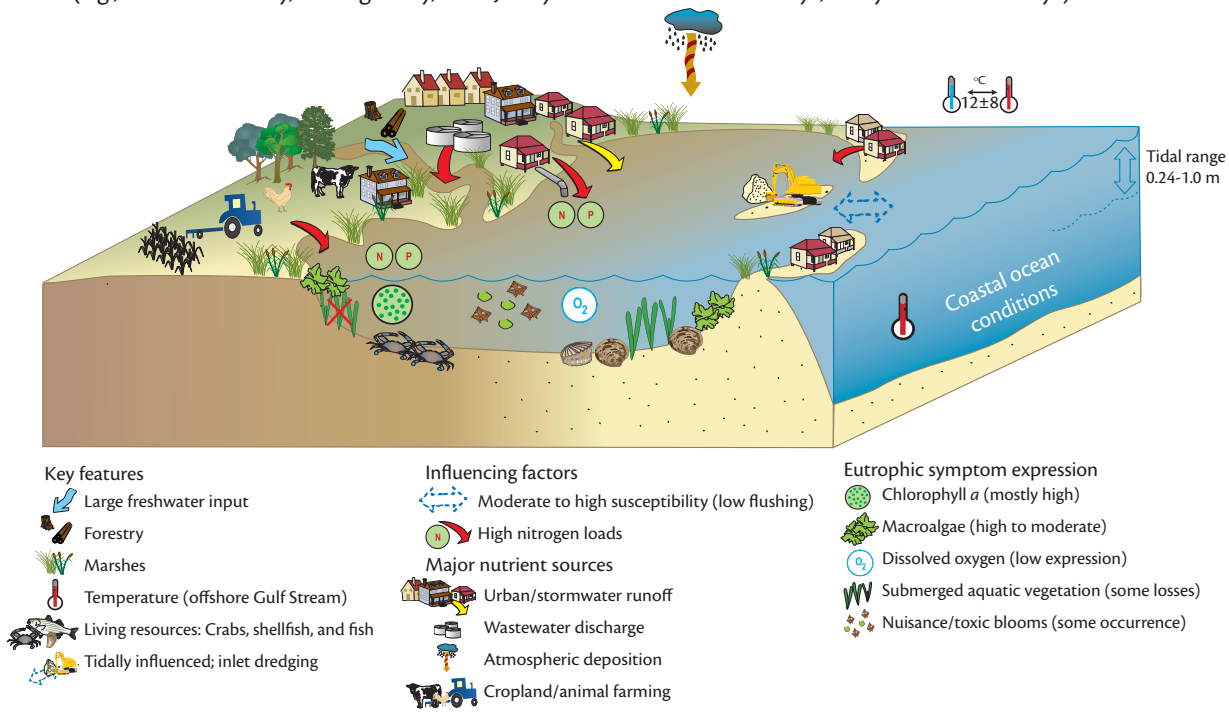
The mid-Atlantic region contains many coastal lagoons such as the one seen here. Assateague Island is a barrier island that protects Sinepuxent Bay, Maryland.

Figure 4.5. Conceptual diagram of mid-Atlantic key features, major nutrient sources, and resulting symptoms.

a. drowned river valleys
(e.g., Chesapeake Bay, Delaware Bay, Long Island Sound, Buzzards Bay, Narragansett Bay)



b. coastal lagoons
(e.g., Great South Bay, Barnegat Bay, New Jersey and Delaware Inland Bays, Maryland Coastal Bays)



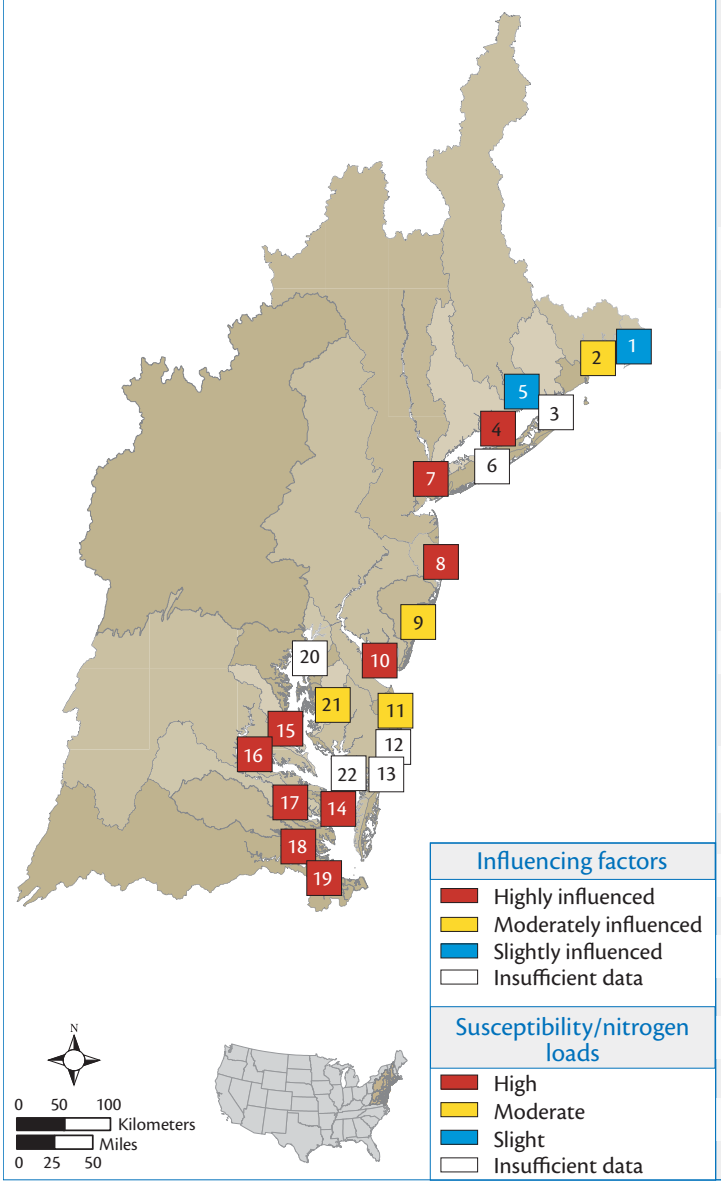
Influencing factors

- The majority of evaluated systems had moderate or high influencing factors.

Nitrogen loads (measured as the ratio of watershed to oceanic nitrogen inputs, see *Chapter 2: Approach*) in this region are mostly considered high, although for six systems, load estimates were unknown (Figure 4.6). All of the mid-Atlantic systems are characterized as moderately to highly susceptible to development of nutrient-related problems. The 14 that are highly susceptible include the coastal lagoons with low dilution and low flushing capabilities, as well as some estuaries that have lower freshwater inputs and smaller tidal ranges. Of the primary nutrient inputs identified for these systems, agricultural activities, wastewater treatment, and urban runoff were the most frequently noted sources. Other sources include onsite septic tanks, combined sewer overflow, and atmospheric deposition. There were no significant differences in the sources of nutrients between the drowned river valleys and coastal lagoons. The combination of higher susceptibility to nutrients and moderate to high nitrogen loads results in these systems having mostly moderate to high influencing factor scores (Figure 4.6)

Figure 4.6. Map of influencing factors ratings, ratings of components of influencing factors, and 1999 ratings in the mid-Atlantic region.

Influencing factors: 2004



Influencing factors: comparisons

Estuary	2004 Influencing factors	2004 Susceptibility	2004 Nitrogen loads	1999 Influencing factors
1. Buzzards Bay	Slightly influenced	Moderately influenced	Slightly influenced	Slightly influenced
2. Narragansett Bay	Moderately influenced	Moderately influenced	Moderately influenced	Highly influenced
3. Gardiners Bay	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
4. Long Island Sound	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
5. Connecticut River	Slightly influenced	Slightly influenced	Highly influenced	Slightly influenced
6. Great South Bay	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
7. Hudson River/Raritan Bay	Highly influenced	Moderately influenced	Highly influenced	Highly influenced
8. Barnegat Bay	Highly influenced	Highly influenced	Highly influenced	Highly influenced
9. New Jersey Inland Bays	Moderately influenced	Highly influenced	Moderately influenced	Highly influenced
10. Delaware Bay	Highly influenced	Moderately influenced	Highly influenced	Highly influenced
11. Delaware Inland Bays	Moderately influenced	Highly influenced	Slightly influenced	Highly influenced
12. N. Maryland Coastal Bays (Isle of Wight/Assawoman)	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
13. S. Maryland Coastal Bays (Chincoteague/Sinepuxent)	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
14. Chesapeake Bay Mainstem	Highly influenced	Highly influenced	Highly influenced	Highly influenced
15. Patuxent River	Highly influenced	Highly influenced	Highly influenced	Highly influenced
16. Potomac River	Highly influenced	Highly influenced	Highly influenced	Highly influenced
17. Rappahannock River	Highly influenced	Highly influenced	Highly influenced	Highly influenced
18. York River	Highly influenced	Highly influenced	Moderately influenced	Highly influenced
19. James River	Highly influenced	Moderately influenced	Highly influenced	Highly influenced
20. Chester River	Insufficient data	Highly influenced	Insufficient data	Highly influenced
21. Choptank River	Moderately influenced	Highly influenced	Slightly influenced	Highly influenced
22. Tangier/Pocomoke Sounds	Insufficient data	Highly influenced	Insufficient data	Highly influenced

Overall eutrophic condition

- This was the most impacted region; the majority of systems had a moderate high to high overall eutrophic condition rating.
- High chlorophyll *a* symptom expression was reported for the majority of systems.
- The majority of systems showing changes have worsened since the early 1990s.

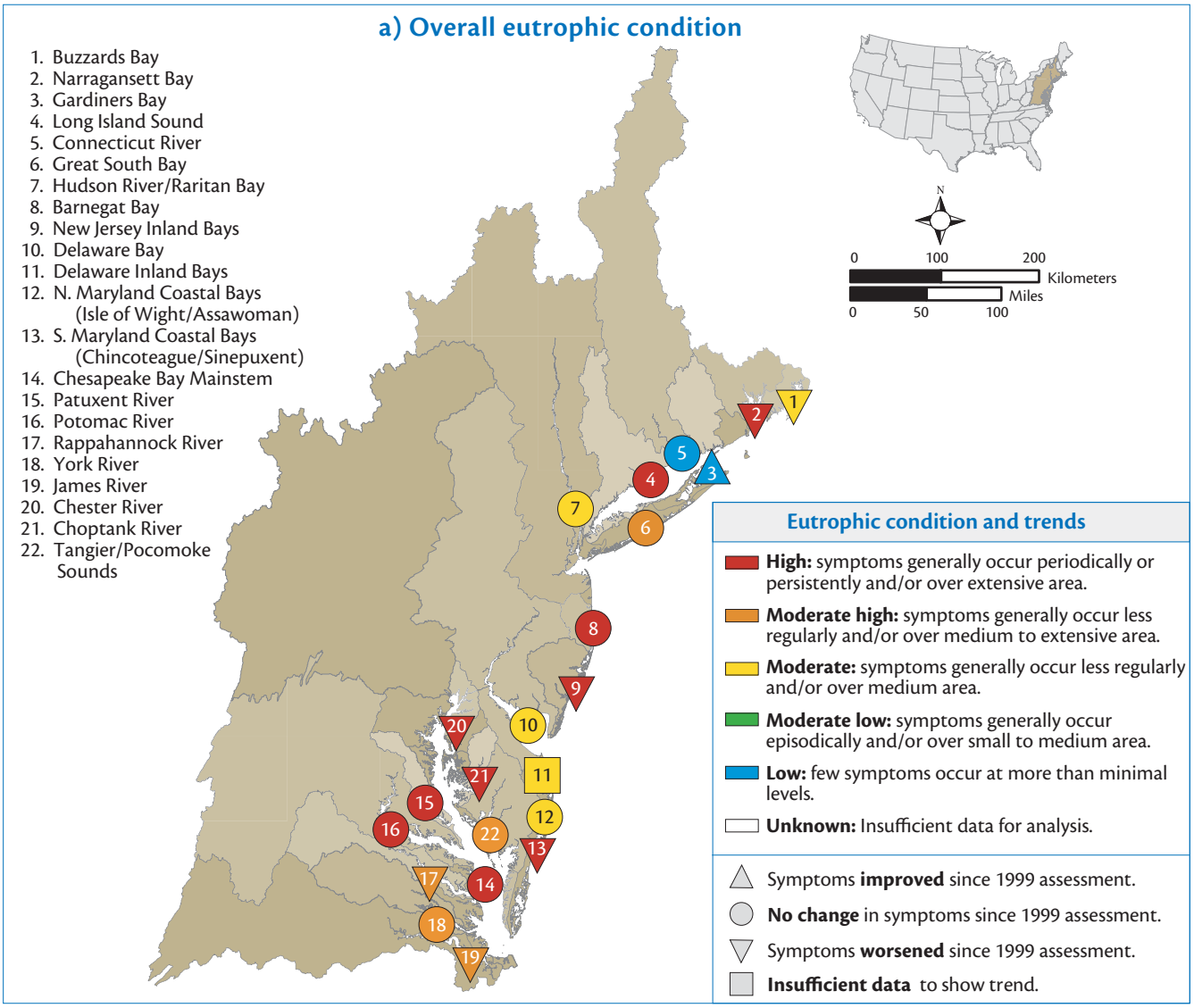
The mid-Atlantic region is the most impacted of all the NEEA regions, with the majority of assessed systems having moderate high to high overall eutrophic condition (Figure 4.7a-b). Only two of the assessed systems had a low overall eutrophic condition (Gardiners Bay and Connecticut River).

The mid-Atlantic has the most complete dataset of all the regions, with overall eutrophic conditions assessed for all systems. The fifteen systems with moderate high to high overall eutrophic conditions are distributed throughout the region and show various combinations of symptoms. All except Narragansett Bay had high levels of chlorophyll *a* and dissolved oxygen problems. Many also have problems with nuisance/toxic blooms. The coastal lagoons received more highly impacted scores as a group than the drowned river estuaries. The overall confidence in eutrophic condition assessment for the region was moderate, the highest of any of the regions.

Eutrophic symptom expressions

More than half of the systems in this region exhibited high levels of at least one of the five symptoms.

Figure 4.7. (a) Map of overall eutrophic condition (OEC) and (b) the combination of individual eutrophic symptoms which constitute OEC ratings in the mid-Atlantic region.



However, many systems had two symptoms with a high score. Of the primary symptoms, chlorophyll *a* levels were the most pronounced, with sixteen systems exhibiting high and only three systems exhibiting low expression (Figure 4.7b). Macroalgae conditions were moderate in five and high in five systems.

Nuisance/toxic blooms were the most significant of the secondary symptoms, with twelve systems exhibiting moderate to high levels of nuisance/toxic blooms. Dissolved oxygen problems occurred at moderate to high levels in seven systems. Five systems experienced moderate to high level losses of submerged aquatic vegetation since the early 1990s.

Changes in eutrophic condition since the 1990s

Overall eutrophic conditions have worsened in eight systems and improved in one since the early 1990s (Figure 4.7a-b). A greater number of systems exhibited worsening (with the exception of SAV) rather than improving eutrophic symptoms. Submerged aquatic vegetation improved in more systems than worsened.

Gardiners Bay demonstrated notable improvements since the 1990s in chlorophyll a and nuisance/toxic blooms. In Gardiners Bay, decreased nitrogen loads and chlorophyll *a* levels contributed to an improved overall eutrophic condition score. However, the absence of SAV data in 2004 for the system versus a high impact in 1999 could have biased the results in this case.

b) Overall eutrophic condition & eutrophic symptoms

Estuary	Overall eutrophic condition	Overall confidence expression	Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/toxic blooms	SAV
1. Buzzards Bay	Moderate	**	Moderate high	Moderate	Low	Moderate	Low
2. Narragansett Bay	High	**	Moderate	High	High	Moderate	Low
3. Gardiners Bay	Moderate high	**	Moderate high	Low	Low	Moderate high	Insufficient data
4. Long Island Sound	High	**	High	Moderate high	High	Moderate high	Low
5. Connecticut River	Low	*	Insufficient data	Insufficient data	Low	Low	Insufficient data
6. Great South Bay	Moderate high	**	High	High	Low	Moderate	Insufficient data
7. Hudson River/Raritan Bay	Moderate	*	High	Insufficient data	Moderate high	Insufficient data	Insufficient data
8. Barnegat Bay	High	***	High	High	Low	High	Moderate
9. New Jersey Inland Bays	High	*	Moderate high	High	Low	Low	High
10. Delaware Bay	Moderate	***	High	Low	Low	Low	NH
11. Delaware Inland Bays	Insufficient data	***	Moderate	High	Low	Moderate high	Low
12. N. Maryland Coastal Bays (Isle of Wight/Assawoman)	Moderate	***	High	High	Low	Moderate high	Low
13. S. Maryland Coastal Bays (Chincoteague/Sinepuxent)	High	***	High	Moderate	Low	High	Low
14. Chesapeake Bay Mainstem	High	***	High	High	High	High	High
15. Patuxent River	High	**	High	Insufficient data	High	Moderate	Moderate high
16. Potomac River	High	***	High	Insufficient data	Moderate	High	Moderate high
17. Rappahannock River	Moderate high	**	High	Low	Moderate	High	High
18. York River	Moderate	***	High	High	Moderate high	High	Moderate high
19. James River	Moderate high	**	High	Low	Low	High	Low
20. Chester River	High	**	High	Insufficient data	High	Insufficient data	Low
21. Choptank River	High	***	High	Moderate high	Low	High	Moderate high
22. Tangier/Pocomoke Sounds	Moderate	**	High	Insufficient data	Low	Insufficient data	Moderate

Eutrophic condition in 2004

- High
- Moderate high
- Moderate
- Moderate low
- Low
- Insufficient data
- NH Not historically observed

Overall confidence expression in 2004

- *** High
- ** Moderate
- * Low

Change in eutrophic condition since 1999 assessment

- Improved
- No change
- Worsened
- Insufficient data

Future outlook

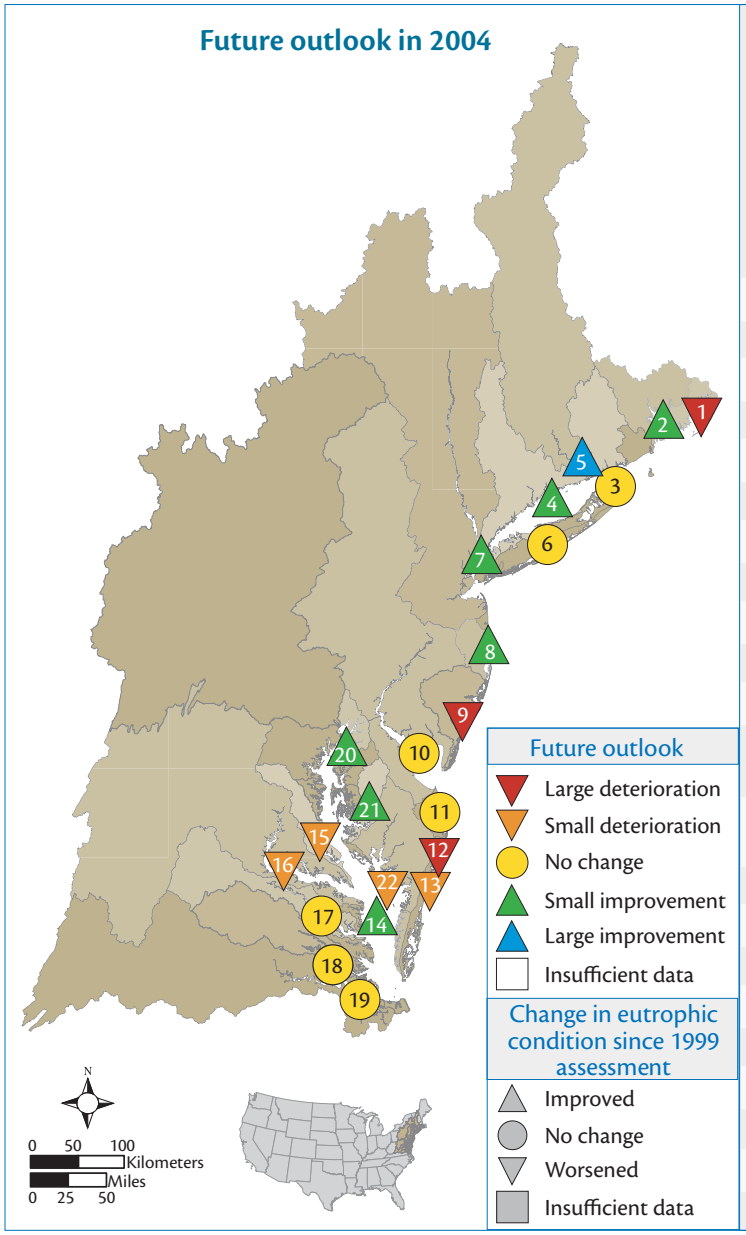
- The assessment revealed a north-south gradient; conditions were mostly expected to improve in the northern and worsen in the southern systems.
- Future outlook was more optimistic than in the early 1990s, though the majority of 1990s predictions have not yet been realized.

Eutrophic conditions are expected to worsen significantly in three systems and to a lesser degree in four others (Figure 4.8). These predictions are based on expected nutrient load increases from wastewater treatment, septic tanks, agriculture, and urban runoff. The coastal population in this region is expected to increase, resulting in nutrient load increases.

Of the eight systems expected to improve, only the Connecticut River is expected to do so significantly due to reductions in upstream nutrient sources. Combined sewer overflow improvements are expected to result in improvements to Barnegat Bay.

The 2004 future outlook is more optimistic than it was in the early 1990s, predicting that more systems will improve than worsen. For the systems where an evaluation was possible, the future outlook from the 1990s has been realized in ten systems but not for 12 others (Figure 4.8). It must be kept in mind that these expected changes were for the year 2020. While some areas demonstrate condition changes sooner than

Figure 4.8. Future outlook in 2004 and comparison with 1999 future outlook.



Future outlook comparisons

Estuary	Future outlook in 2004	Actual change in eutrophic condition (1999–2004)	Future outlook in 1999
1. Buzzards Bay	Large deterioration	Worsened	No change
2. Narragansett Bay	Small improvement	Worsened	No change
3. Gardiners Bay	No change	Improved	No change
4. Long Island Sound	Small improvement	No change	No change
5. Connecticut River	Large improvement	No change	No change
6. Great South Bay	No change	No change	No change
7. Hudson River/Raritan Bay	Small improvement	No change	No change
8. Barnegat Bay	Small improvement	No change	Small deterioration
9. New Jersey Inland Bays	Large deterioration	Worsened	Large deterioration
10. Delaware Bay	No change	No change	No change
11. Delaware Inland Bays	No change	Insufficient data	No change
12. N. Maryland Coastal Bays (Isle of Wight/Assawoman)	Large deterioration	No change	Small deterioration
13. S. Maryland Coastal Bays (Chincoteague/Sinepuxent)	Small deterioration	Worsened	Small deterioration
14. Chesapeake Bay Mainstem	Small improvement	No change	Small deterioration
15. Patuxent River	Small deterioration	No change	Small deterioration
16. Potomac River	Small deterioration	No change	Small deterioration
17. Rappahannock River	No change	Worsened	Small deterioration
18. York River	No change	No change	Large deterioration
19. James River	No change	Worsened	Small deterioration
20. Chester River	Small improvement	Worsened	Small deterioration
21. Choptank River	Small improvement	Worsened	Small deterioration
22. Tangier/Pocomoke Sounds	Small deterioration	No change	Large deterioration

Jeff Folino, Richard Stockton College of New Jersey

Improvements to sewage systems are expected to improve water quality in Barnegat Bay, New Jersey.

others, the accuracy of these particular predictions should be addressed in 2020, or predictions should be made for a shorter time scale.

Assessment of Estuarine Trophic Status (ASSETS)

An ASSETS rating, (combination of influencing factors, OEC, and future outlook), was made for 16 systems, with nine systems rated as bad (Narragansett Bay, Barnegat Bay, Patuxent River, Potomac River, Rappahannock River, Choptank River and Chesapeake Bay mainstem, Long Island Sound, New Jersey Inland Bays), two as poor (York and James Rivers), four as moderate (Buzzards Bay, Hudson River/Raritan Bay, Delaware Bay, Delaware Inland Bays) and one as high (Connecticut River).

Impaired uses

- More than half the systems in this region had impacts to living resources.
- Causes of impairments included agriculture (crops and animal operations), wastewater treatment, urban runoff, atmospheric deposition, onsite septic tanks, and combined sewer overflow.
- Thirteen systems were affected by human use impairments (primarily shellfishing, and recreational and commercial fishing).

More than half of the systems in this region (14) had impacts to living resources from eutrophication. Eight systems had considerable impacts (Narragansett Bay, Barnegat Bay, Patuxent River, Potomac River, Choptank River, Chesapeake Bay Mainstem, Hudson River/Raritan Bay, Tangier/Pocomoke Sounds) while six others had moderate impacts (Buzzards Bay, Long Island Sound, Great South Bay, Rappahannock River, York River, James River) and one had slight impacts (Connecticut River). There is a good correspondence in this region between moderate to high level eutrophic conditions and moderate to considerable impacts to living resources. Notable causes were wastewater treatment, agriculture (crops and animal operations), urban runoff, atmospheric deposition, onsite septic tanks, and combined sewer overflow. Forestry activities were a problem only in the York River watershed. Estuarine and lagoonal systems demonstrated similar impacts to living resources.

For the thirteen systems reporting use impairments, the most often reported impairments were to fishing (shellfish, recreational, and commercial). Impairments were also reported for aesthetics, fish consumption, and swimming. There is no difference in the use impairments between the estuarine and lagoonal systems.

Potential management concerns

The nutrient sources contributing to living resource and use impairments were wastewater treatment, agriculture, urban runoff, atmospheric deposition, onsite septic tanks, and combined sewer overflow. Future increases in nutrient load from these sources are expected as a result of an overall increase in coastal populations. It is important that these sources be given management attention, since these systems for the most part are already moderately to highly impacted and many are expected to worsen.

National Oceanic and Atmospheric Administration

Children exploring tide pools along the shores of Buzzards Bay, Massachusetts. Monitoring and managing eutrophic conditions will ensure continued enjoyment of the estuary.

Data gaps and research needs

Monitoring

Although the data in this region is the most robust nationally, it is still inadequate to document trends (particularly restoration) in many estuaries. Additional monitoring is needed so that trends can be better evaluated in the future. In particular, monitoring data for both chlorophyll *a* and macroalgae are needed, as well as a standardized assessment method for the latter. Improved estimates of nutrient sources and loads are also needed.

Research

Wet atmospheric deposition is currently characterized by the National Atmospheric Deposition Program (NADP) network. In general, better estimates of all atmospheric sources are needed, though dry deposition is in particular need of greater characterization. Additionally, a focus should be placed on determining the importance of the localized effects of animal feeding operations. Determining the nutrient inputs to and exports from coastal watersheds is also a research challenge. Nutrients are either stored within the watersheds (N or P in biomass, soils, or groundwater) or denitrified (N), and the importance of these pathways should be explored. And finally, the ability of living resources to tolerate eutrophic conditions should be examined.

Management

Measures should be implemented to guide development so that it does not grow as sprawl (vertical vs horizontal growth). In this way, waste streams can be concentrated for more efficient treatment and possible recycling to agricultural areas. Vertical growth must be accompanied by advanced treatment or recycling in order to prevent increased nutrient loading. Such management measures should be implemented and vigorously enforced at both the regional and national level, as many airsheds and watersheds exceed political boundaries. Examples of where this has been effective are the Clean Air Act, leading to reduced sulfate emissions, the ban of phosphorus in detergents, and the permitting of point sources.

USDA Natural Resources Conservation Service

Studying the impacts of animal feeding operations on nutrient loads and eutrophic conditions could help communities in the mid-Atlantic region design and implement management plans, and potentially reduce these loads.

SOUTH ATLANTIC REGION

- Diverse range of eutrophic conditions occurred in this region; the number of estuaries with high eutrophic condition was similar to the number of estuaries with low eutrophic condition.
- A large number of systems had moderate dissolved oxygen symptom expression.

The South Atlantic region includes 22 systems, encompassing more than 12,182 km² of water surface area. The region is comprised of extensive barrier and sea islands which parallel the shoreline (Figure 4.9). This coastal environment consists of shallow lagoonal estuaries, extensive tidal marshes, and drowned river valleys. Dendritic systems with extensive salt marshes are mostly found in the northern part of this region. Regionally, tidal ranges vary from 0.15 to 2.2 m. In the northern part of this region, tidal range is higher on average (1.3 m) than in the Florida systems (0.48 m), and influences mixing in the water column, primarily near the inlets. In the northern systems, depths are also greater, averaging 3.2 m compared to the Florida systems' 1.4 m. The overall regional depth range is 0.65–19.5 m. Climate is temperate to subtropical, with annual mean temperatures of 19°C, 36 frost days per year, and an average precipitation of 1.3 m per year. Estuarine circulation patterns are dominated mainly by wind and seasonal freshwater inflow in North Carolina, and mainly by freshwater inflow and tides in South Carolina and Georgia (Figure 4.9a). Circulation along the Florida coast is dominated by wind forcing and human engineering (Figure 4.9b). Dominant land uses are agriculture and industry, and to a lesser extent, forestry. The average regional population density is six people per km² of catchment, with the density in the northern catchments much less on average (3 people km^{-2}) than in Florida catchments (43 people km^{-2}). Major population centers include Miami and Jacksonville, Florida and Savannah, Georgia.

National Oceanic and Atmospheric Administration

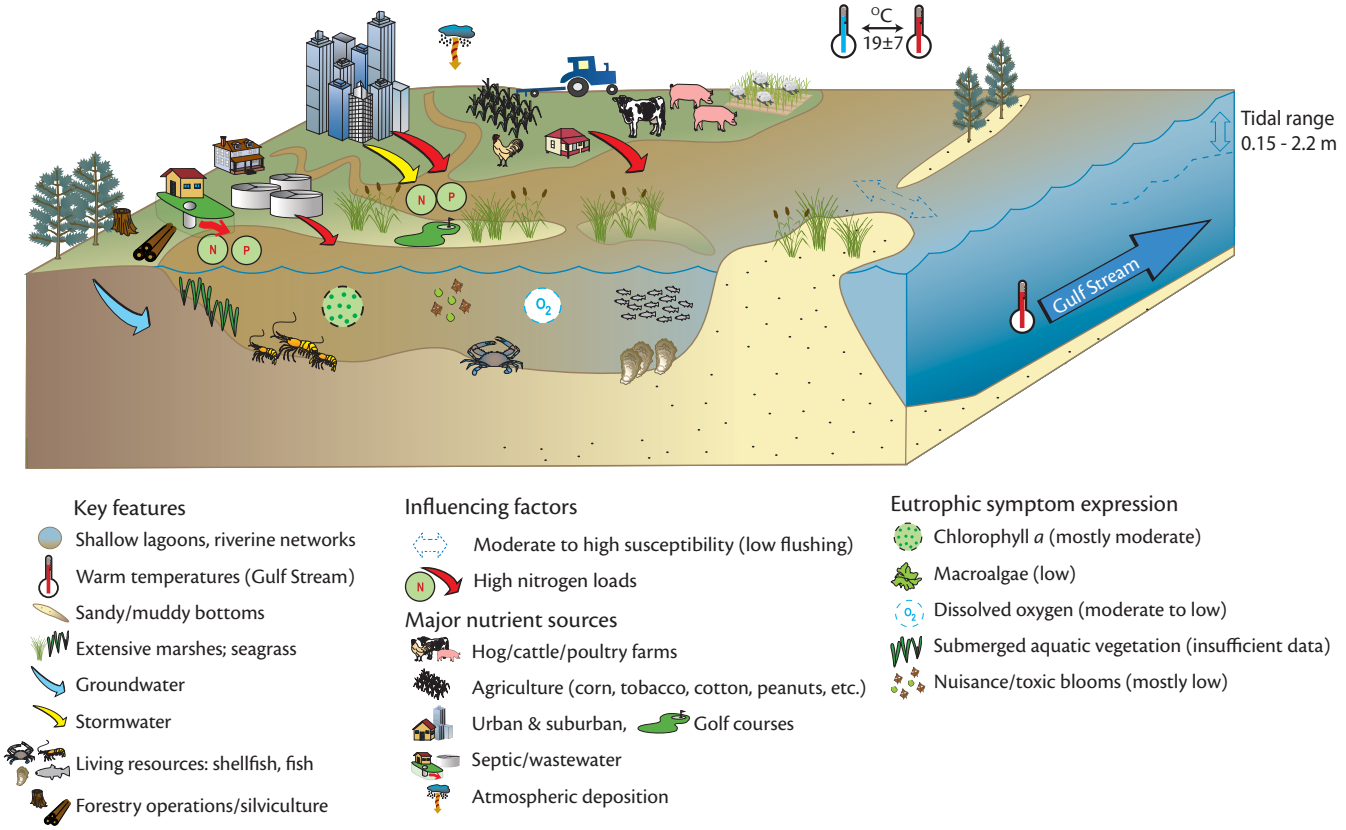
The extensive barrier islands in the South Atlantic region support wetlands such as the one pictured above near Charleston, South Carolina.

National Oceanic and Atmospheric Administration

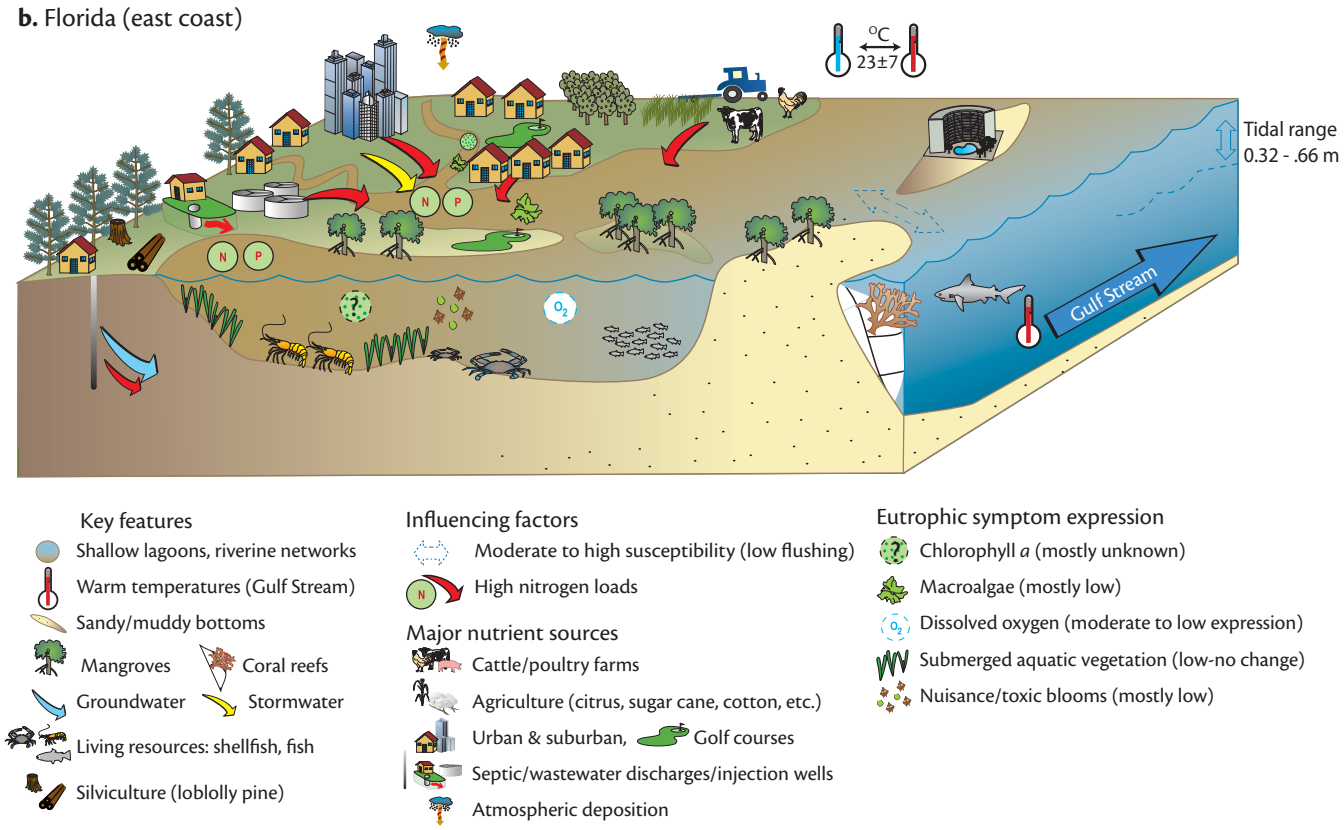
The South Atlantic region has many mangrove forests such as this one in southern Florida.

Figure 4.9. Conceptual diagram of South Atlantic key features, major nutrient sources, and resulting symptoms.

a. Georgia to North Carolina



b. Florida (east coast)



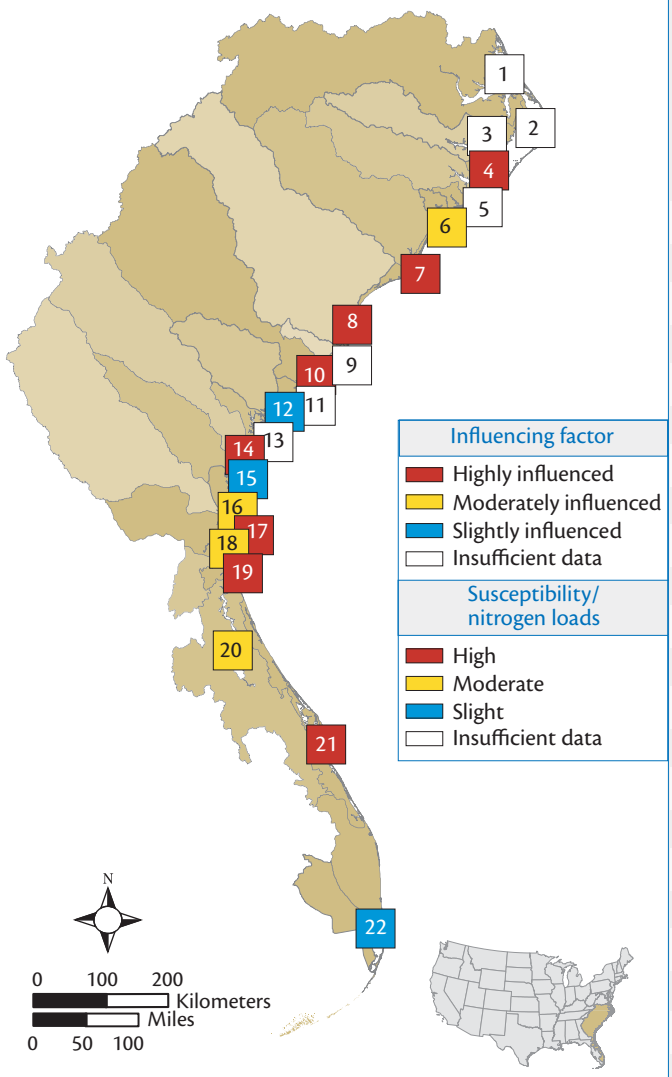
Influencing factors

- Factors influencing eutrophication were spatially variable in the South Atlantic region.

Nitrogen loads in this region, represented as the ratio of land based to oceanic sources, were highly variable. Thirteen have high or moderate loading, only two systems have low nitrogen loads (Figure 4.10). The dominant sources of nutrients to the systems in this region are agricultural activities (animal operations and crops), wastewater treatment, atmospheric deposition, urban runoff, and exurban (i.e., beyond urban areas) development. The most notable nutrient source is animal operations, which is a local problem in North and South Carolina. Susceptibility of these systems is mostly moderate or high due to the restricted exchange through inlets and moderate to low dilution capability. Influencing factors are a reflection of the generally high loads and moderate to high susceptibility to develop problems.

Figure 4.10. Map of influencing factors ratings, ratings of components of influencing factors, and 1999 ratings in the South Atlantic region.

Influencing factors: 2004



Influencing factors: comparisons

Estuary	2004 Influencing factors	2004 Susceptibility	2004 Nitrogen loads	1999 Influencing factors
1. Albemarle Sound	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
2. Pamlico Sound	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
3. Pamlico/Pungo Rivers	Insufficient data	Highly influenced	Insufficient data	Highly influenced
4. Neuse River	Highly influenced	Highly influenced	Highly influenced	Highly influenced
5. Bogue Sound	Insufficient data	Highly influenced	Insufficient data	Slightly influenced
6. New River	Moderately influenced	Highly influenced	Slightly influenced	Highly influenced
7. Cape Fear River	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
8. Winyah Bay	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
9. N. Santee/S. Santee Rivers	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
10. Charleston Harbor	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
11. Stono/North Edisto Rivers	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
12. St. Helena Sound	Slightly influenced	Slightly influenced	Highly influenced	Slightly influenced
13. Broad River	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
14. Savannah River	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
15. Ossabaw Sound	Slightly influenced	Slightly influenced	Highly influenced	Slightly influenced
16. St. Catherines/Sapelo Sounds	Moderately influenced	Moderately influenced	Moderately influenced	Slightly influenced
17. Altamaha River	Highly influenced	Moderately influenced	Highly influenced	Moderately influenced
18. St. Andrew/St. Simons Sounds	Moderately influenced	Moderately influenced	Moderately influenced	Slightly influenced
19. St. Marys River/Cumberland Sound	Highly influenced	Highly influenced	Highly influenced	Moderately influenced
20. St. Johns River	Moderately influenced	Highly influenced	Slightly influenced	Moderately influenced
21. Indian River	Highly influenced	Highly influenced	Highly influenced	Moderately influenced
22. Biscayne Bay	Slightly influenced	Slightly influenced	Highly influenced	Insufficient data

Overall eutrophic condition

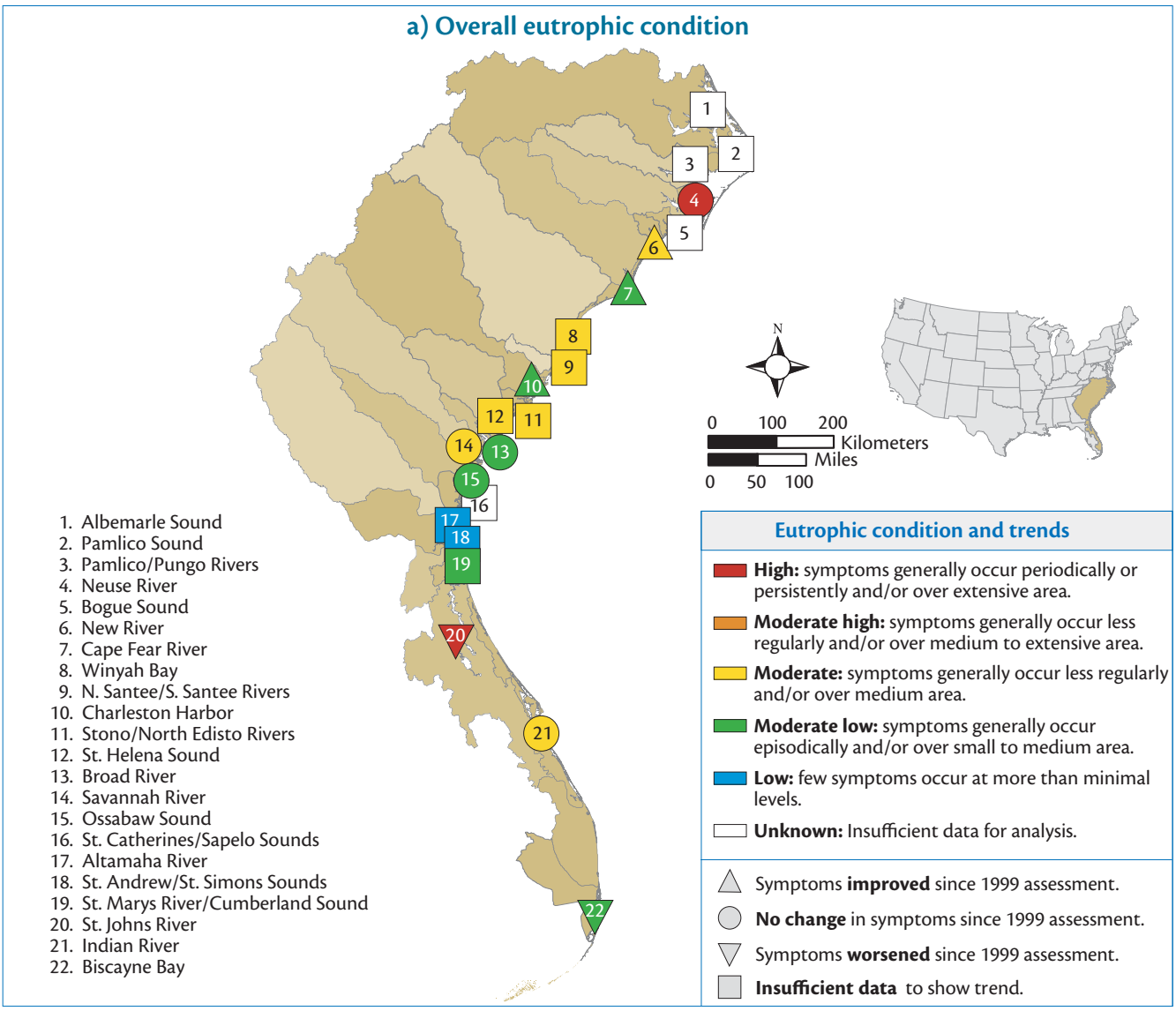
- Most systems in this region had moderate or low eutrophic condition
- The systems with a rating of high had problematic levels of chlorophyll *a* and nuisance/toxic blooms.

The overall eutrophic condition in this region is mostly moderate and low (15 systems, Figure 4.11), though two systems exhibit a high rating. Symptoms leading to the higher eutrophic conditions were predominantly chlorophyll *a* and nuisance/toxic blooms. The confidence in the overall condition assessment was mostly moderate and high for the systems assessed. However, since there were additional estuaries (5) within the region for which data were unavailable, a more extensive characterization is needed in order to properly observe regional trends.

Eutrophic symptom expressions

Like most other regions, high chlorophyll *a* was the most common sign of eutrophication exhibited within the estuaries. Of the 17 assessed estuaries, three had high chlorophyll *a* symptom expressions. While

Figure 4.11. (a) Map of overall eutrophic condition (OEC) and (b) the combination of individual eutrophic symptoms which constitute OEC ratings in the South Atlantic region.



most other symptoms were generally low, dissolved oxygen was moderate in many estuaries.

Two systems in the region (the Neuse and St. Johns Rivers) had two or more high symptom expressions, indicating that they are more eutrophic than the other systems assessed. Symptoms with high ratings in these estuaries were macroalgae in the St. Johns River, chlorophyll *a*, and nuisance/toxic blooms for both the Neuse River and St. Johns River. Data for macroalgae and SAV loss were sparse. For many systems, these indicators have not historically been observed (Figure 4.11b). A different indicator should be developed and used in these systems.

Changes in eutrophic condition since the 1990s

Since the first assessment, conditions in three South Atlantic systems have improved, while conditions in two have worsened. A trend analysis was not possible for most systems because the indicators used in each time frame were incomparable (Figure 4.11). Although it is not explicitly reflected by this assessment, dissolved oxygen problems are known to have increased in some other South Atlantic systems. These estuaries are well-mixed, and therefore, the declining dissolved oxygen levels are of great concern (Verity et al. 2006).

b) Overall eutrophic condition & eutrophic symptoms

Estuary	Overall eutrophic condition	Overall confidence expression	Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/toxic blooms	SAV
1. Albemarle Sound	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
2. Pamlico Sound	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Moderate	Insufficient data
3. Pamlico/Pungo Rivers	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
4. Neuse River	High	**	High	Insufficient data	Worsened	High	Insufficient data
5. Bogue Sound	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
6. New River	Moderate	***	High	Low	Low	Worsened	Insufficient data
7. Cape Fear River	Moderate low	**	Moderate	Low	Low	Low	Insufficient data
8. Winyah Bay	Moderate	*	Moderate	NH	Moderate	Low	NH
9. N. Santee/S. Santee Rivers	Moderate	*	Moderate	NH	Moderate	Low	NH
10. Charleston Harbor	Moderate low	**	Moderate	NH	Worsened	Low	NH
11. Stono/North Edisto Rivers	Moderate	**	Moderate	NH	Moderate	Low	NH
12. St. Helena Sound	Moderate	*	Improved	NH	Moderate	Moderate	NH
13. Broad River	Moderate low	**	Improved	NH	Worsened	Low	NH
14. Savannah River	Moderate	**	Moderate	Low	Moderate	Low	NH
15. Ossabaw Sound	Moderate low	**	Insufficient data	Low	Improved	Low	NH
16. St. Catherines/Sapelo Sounds	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	NH
17. Altamaha River	Low	**	Insufficient data	Low	Low	Low	NH
18. St. Andrew/St. Simons Sounds	Low	*	Insufficient data	Low	Insufficient data	Low	NH
19. St. Marys River/Cumberland Sound	Moderate low	**	Insufficient data	Low	Moderate	Low	NH
20. St. Johns River	Worsened	***	High	Worsened	Moderate	Worsened	Low
21. Indian River	Moderate	**	Low	Moderate	Low	Improved	Low
22. Biscayne Bay	Worsened	***	Low	Low	Improved	Low	Low

Eutrophic condition in 2004

- High
- Moderate high
- Moderate
- Moderate low
- Low
- Insufficient data
- NH Not historically observed

Overall confidence expression in 2004

- *** High
- ** Moderate
- * Low

Change in eutrophic condition since 1999 assessment

- Improved
- No change
- Worsened
- Insufficient data

Future outlook

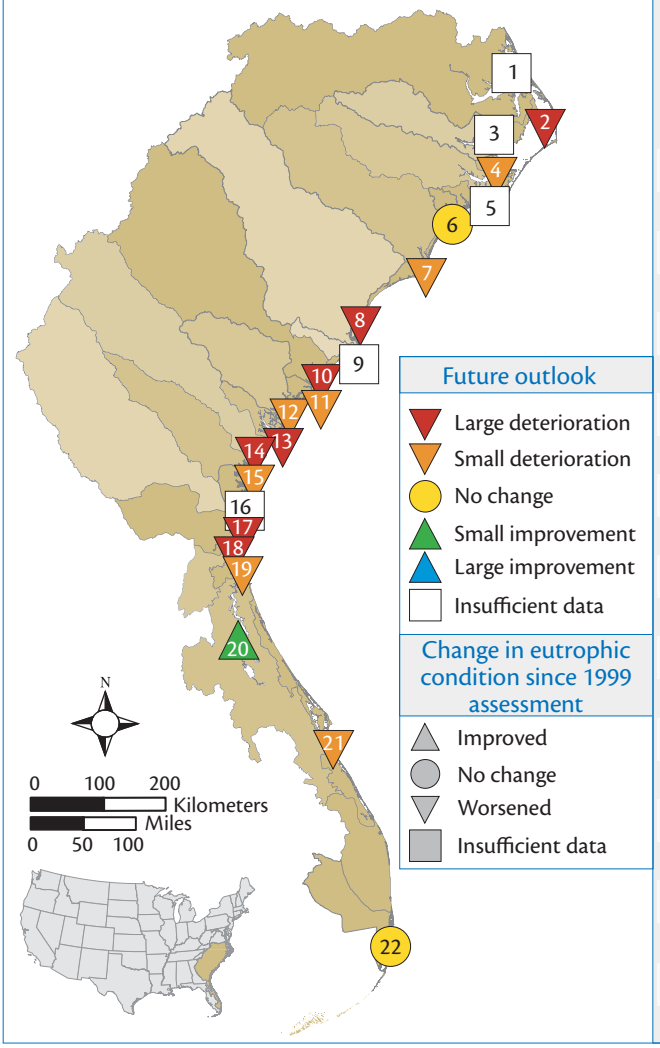
- Predictions were bleak; most evaluated systems were expected to worsen. Only St. Johns River was expected to improve.
- The future outlook has not changed since the early 1990s.
- Predictions have been fulfilled for four out of ten systems for which an evaluation could be made.

Based on the survey respondents, 14 estuaries throughout the region are predicted to develop worsening eutrophication conditions and seven are expected to worsen significantly (Figure 4.12) by 2020. Most of these systems presently exhibit low or moderate conditions. Worsening conditions are based on expectations of increased nutrient loads, mostly to a low or moderate degree. The Indian River is the exception, with a large increase (50-100% of present loads) in atmospheric and urban nitrogen load predicted as a result of expected population increases. Most nutrient load increases are expected to come from increases in wastewater treatment, atmospheric deposition, animal operations, exurban development (i.e., beyond the boundaries of urban regions), and onsite septic tanks (St. Helena Sound only). Increasing development and coastal population contributes greatly to the sources named above.

Only one system (St. Johns River) is expected to improve in the future as a result of a planned Total

Figure 4.12. Future outlook in 2004 and comparison with 1999 future outlook.

Future outlook in 2004



Future outlook comparisons

Estuary	Future outlook in 2004	Actual change in eutrophic condition (1999 - 2004)	Future outlook in 1999
1. Albemarle Sound	Insufficient data	Insufficient data	Small deterioration
2. Pamlico Sound	Large deterioration	Insufficient data	No change
3. Pamlico/Pungo Rivers	Insufficient data	Insufficient data	No change
4. Neuse River	Small deterioration	No change	No change
5. Bogue Sound	Insufficient data	Insufficient data	Small improvement
6. New River	No change	Improved	Small improvement
7. Cape Fear River	Small deterioration	Improved	No change
8. Winyah Bay	Large deterioration	Insufficient data	No change
9. N. Santee/S. Santee Rivers	Insufficient data	Insufficient data	No change
10. Charleston Harbor	Large deterioration	Improved	Large deterioration
11. Stono/North Edisto Rivers	Small deterioration	Insufficient data	No change
12. St. Helena Sound	Small deterioration	Insufficient data	Small improvement
13. Broad River	Large deterioration	No change	Large deterioration
14. Savannah River	Large deterioration	No change	Small deterioration
15. Ossabaw Sound	Small deterioration	No change	Small deterioration
16. St. Catherines/Sapelo Sounds	Insufficient data	Insufficient data	Large deterioration
17. Altamaha River	Large deterioration	Insufficient data	Small deterioration
18. St. Andrew/St. Simons Sounds	Large deterioration	Insufficient data	Large deterioration
19. St. Marys River/Cumberland Sound	Small deterioration	Insufficient data	Large deterioration
20. St. Johns River	Small improvement	Worsened	Large deterioration
21. Indian River	Small deterioration	No change	Large deterioration
22. Biscayne Bay	No change	Worsened	Large deterioration

National Oceanic and Atmospheric Administration

Wildlife such as this great blue heron in a North Carolina estuary are also affected by eutrophic impacts to fisheries.

Maximum Daily Load (TMDL). If implemented, the TMDL will reduce nutrient loads from National Pollution Discharge Elimination System facilities. However, increasing development and other exacerbating factors, such as water withdrawals and dredging, are increasing residence time in St. Johns, which may increase susceptibility and counterbalance improvements.

The future outlook at present is the same as in the early 1990s–worsening conditions expected in the majority of systems. For the ten systems where evaluation was possible, the future outlook from the 1990s has been realized for four systems but as yet does not agree with 2004 results for six systems (Figure 4.12). This result may stem from the fact that these expected changes are for the year 2020. While some areas demonstrate condition changes sooner than others, the accuracy of these particular predictions should be addressed in 2020, or predictions should be made for a shorter time scale.

Assessment of Estuarine Trophic Status (ASSETS)

ASSETS ratings were made for 12 systems, with the Neuse River and St. Johns River rated as bad, Winyah Bay, Savannah River and Indian River rated as poor, six systems as moderate (St. Andrew/St. Simons Sound, Cape Fear River, St. Helena Sound, Charleston Harbor, New River, and Ossabaw Sound), and Biscayne Bay rated as good. There were two systems (Altamaha River and St. Marys River/ Cumberland Sound) for which the ASSETS rating was not made even though all three components, influencing factors, overall eutrophic condition, and future outlook were available. The reason is that these systems have high influencing factors but the eutrophic conditions are low. This is a combination that is flagged for further investigation since it is unlikely that a system can have high inputs but low expression of conditions. This can occur when the susceptibility is low, but for these systems susceptibility is moderate. It is likely that this result is an artifact of incorrectly drawn boundaries of these systems. This would potentially cause incorrect assessment of conditions and susceptibility, since the system boundaries would potentially include different spatial area, flow, and circulation conditions. The boundaries of these systems will be re-evaluated prior to the next assessment. It is also possibly the result of the highly colored water of these systems, which limits algal growth despite high nitrogen input.

Impaired uses

- Two systems hadd considerable, and four moderate or slight impacts to living resources.
- Contributing to impairment were agriculture (crops and animal operations), atmospheric deposition, urban runoff, and wastewater treatment.
- Thirteen systems had human use impairments (primarily shellfish harvesting, and recreational and commercial fishing).
- Living resources were most impaired in systems expressing moderate to high OEC.

Impacts to living resources were reported for eight systems in this region, with two having considerable impairment (Neuse River and St. Johns River), four moderate or slight (New River, Cape Fear River,

National Oceanic and Atmospheric Administration

Commercial and recreational ships on Winyah Bay, SC.

Indian River, Biscayne Bay) and two (Ossabaw Sound, St. Marys River/Cumberland Sound) having no impacts. The level of impact was not reported for the remaining 14 systems. There is a correspondence between eutrophic condition and living resource impacts in both the Neuse and St. Johns Rivers, rated with a high OEC, as well as considerable impacts to living resources. Estuaries with moderate conditions also report impacts to living resources. The most often named causes of impacts to living resources are agriculture (animal operations and crops), urban runoff, wastewater treatment, and atmospheric deposition. Other reported causes are rangeland/pasture and dredging.

Eight systems had human use impairments, mostly to shellfish, fish consumption, swimming, and commercial and recreational fishing. Aesthetics were reported to be impaired for the Neuse River, while boating, tourism, and aesthetics were reported as impaired in St. Johns River.

Caroline Wicks, EcoCheck (NOAA/University of Maryland Center for Env. Science)

Juvenile barracuda in the shallow waters of Fort Zachary Taylor Historic State Park, Key West, Florida.

Potential management concerns

Important management concerns for systems with high and moderate eutrophic conditions are those nutrient sources listed as impacts to living resources (above section). Management measures should be implemented as quickly as possible. Though many of these systems currently exhibit low eutrophication-related impacts, their moderate to high susceptibility, coupled with expected increases in nutrient loading, may lead to worsening conditions more easily than in low susceptibility systems. Additionally, highly susceptible systems with high eutrophic impact will be more difficult to remediate. Thus managers should act now to prevent worsening conditions.

Data gaps and research needs

Monitoring

The need for data in this region is critical. Given the projected increases in population and the high susceptibility of many of the systems, time series data

National Oceanic and Atmospheric Administration

Shrimp boats on the Altamaha River, Georgia.

Caroline Wicks, EcoCheck (NOAA/University of Maryland Center for Environmental Science)

Sunset Key, Florida; Future management plans will have to balance the needs of the ecosystem with recreational activities.

are particularly needed for tracking trends. Presently there are few recent data, and the North Carolina Division of Environment and Natural Resources has cut back on spatial coverage of water quality stations, particularly along barrier islands and large lagoonal systems. Regular monitoring should be a priority in this region, especially in Albemarle, Currituck, and Bogue Sounds, and the Pamlico and Savannah Rivers, which have no regular monitoring.

Research

Load estimates for almost one third of these systems are unknown. A focus for research should be to provide total loads and organic/inorganic nutrient loads as well as identifying the primary sources so that management measures can be applied successfully. Research is needed to determine the importance of local effects from animal feeding operations (e.g., ammonia (NH_3) emissions from pig farms on the North Carolina coast) and runoff from land application of waste. With regard to the indicators used in the assessment, some systems in this region do not have native SAV and macroalgae due partially to the presence of colored water (i.e., blackwater). Therefore, their presence/absence may not be an issue of eutrophication. Indicators will be reevaluated for particular types of systems prior to the next assessment in order to improve accuracy (see *Chapter 6: Improvements*). Additionally, low dissolved oxygen in some systems may be the result of microbial processes rather than decomposition of algae, as shown by Verity et al. (2006). This should be investigated further.

Management

Important management concerns for systems in this region are all related to increased population in the coastal zone and concomitant development. The most notable management concerns are urban runoff, wastewater treatment, and atmospheric deposition for the region. For North and South Carolina, the priority for management should be animal operations.

GULF OF MEXICO REGION

- Due to high nutrient loads and high susceptibility, most estuaries assessed had a high influencing factors rating.
- Only a small proportion of estuaries recorded high or moderate high overall eutrophic condition.
- Systems with moderate or moderate high eutrophic condition were characterized by high, and often worsening, chlorophyll *a* symptoms.

The Gulf of Mexico region includes 37 estuaries and the Mississippi River Plume, encompassing more than 30,577 km² of water surface area. The region is comprised of a gently sloping, lowland part of the Gulf Coastal Plain (Figure 4.13). Estuarine and coastal environments are highly diverse, consisting of unrestricted open bays, semi-enclosed lagoons, tidal marshes, and delta complexes. The freshwater naturally flowing into the estuaries may fluctuate greatly in the Gulf region, and depends upon seasonal rainfall patterns. Average annual precipitation is 0.98 m in the western Gulf region and 1.46 m in the eastern Gulf region, with a regional average of 1.33 m per year. Estuarine circulation patterns are generally wind driven and coastal waters are usually warmer than in other regions due to the subtropical climate, with an average annual temperature of 22°C and 12 frost days per year. Estuaries have fairly low tidal energy (0.03–0.81 m tide range, 0.40 m avg.), and water depths are typically shallow when compared to estuaries in other regions (0.05–7.01 m depth range, 1.85 m average). Land use activity in these watersheds is typically dominated by agriculture. Major population centers include Houston, New Orleans, and Tampa. Average regional population density is 26 people per km².

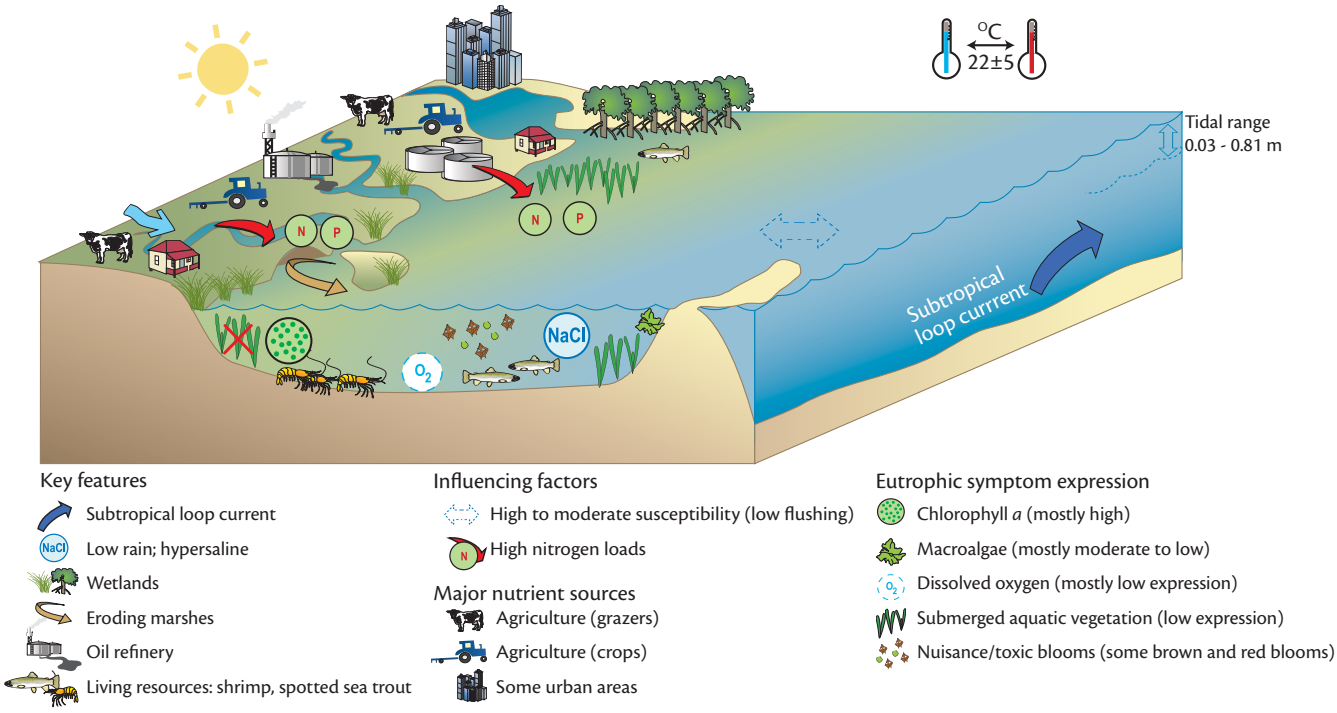
USDA National Resource Conservation Service

The Gulf of Mexico region contains several cypress wetlands such as these along the Mississippi River.

Tom Wazniak, University of Maryland Center for Environmental Science

Wetlands such as these in coastal Lousiana are common in the Gulf region.

Figure 4.13. Conceptual diagram of Gulf of Mexico key features, major nutrient sources, and resulting symptoms.



Tim Carruthers, University of Maryland Center for Environmental Science

Oil extraction rig among eroding wetlands looking towards the Gulf of Mexico, southeast of Houma in coastal Louisiana.

Influencing factors

- Most systems for which an evaluation could be made had high influencing factors.

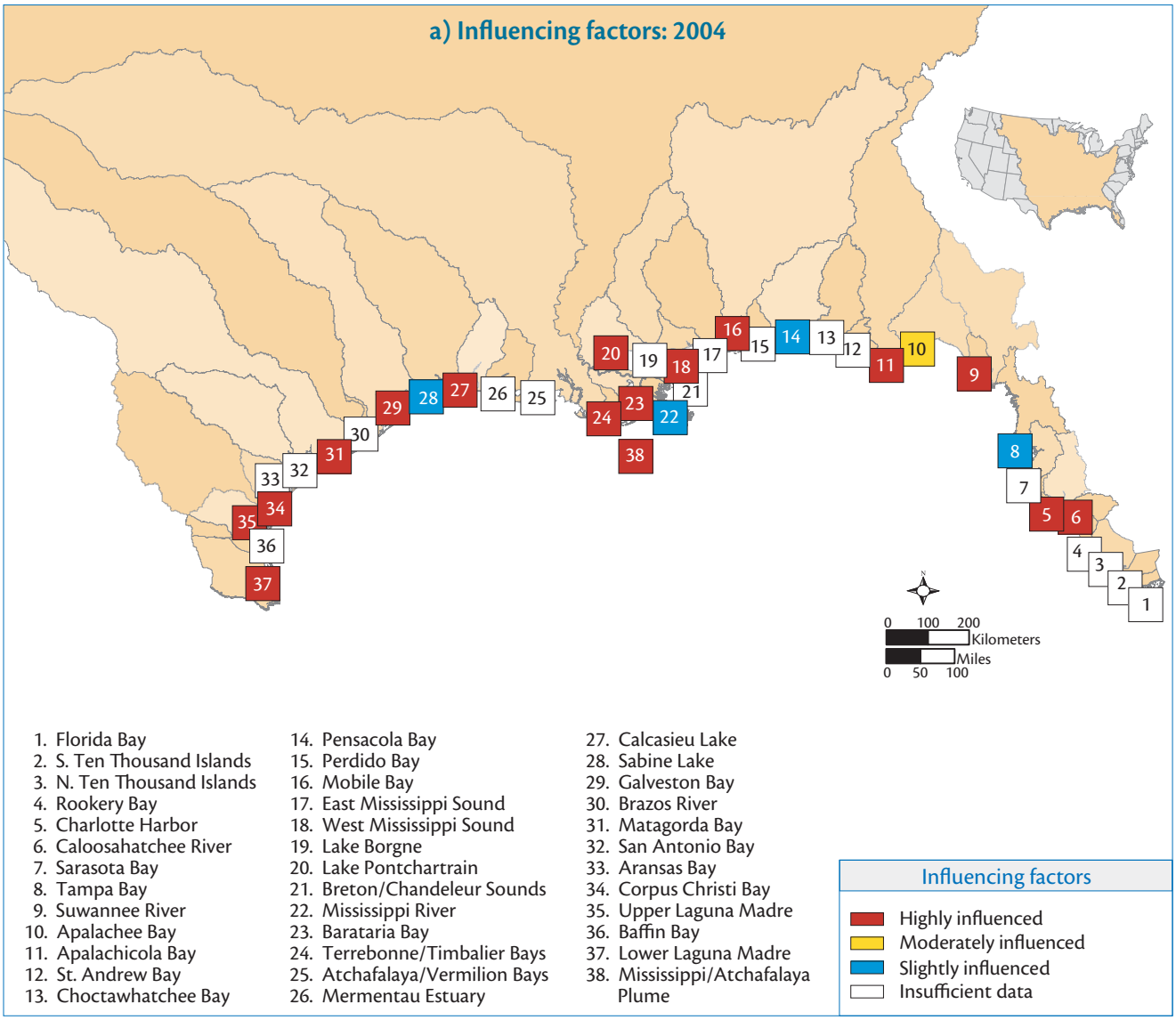
Watershed nitrogen inputs were high in over 80% of the systems assessed. However, nitrogen loading data are fairly limited in the Gulf regions with no information available for approximately half of the systems (Figure 4.14). Nitrogen loading data were considered low for only two of the 38 systems, Tampa and Pensacola Bays. Understandably, the Mississippi River has the largest nutrient load of all U.S. rivers. Nutrient load estimates for the Mississippi were used to calculate influencing factor ratings for both the Mississippi River and Mississippi/Atchafalaya Plume.

In general, the Gulf region has a high human influence because of the high level of agricultural activities. Dominant sources of nutrients to systems in this region are wastewater treatment, urban runoff, and agriculture (crops).

Most estuaries in this region have shallow depths and small tidal ranges, leading to low dilution and flushing rates. As a consequence, most estuaries have either a moderate or high susceptibility to nutrient loading (Figure 4.14).

The combined effects of high nitrogen loads and a moderate or high susceptibility to nutrients results in most systems having a high influencing factors rating (except for Tampa and Pensacola Bays).

Figure 4.14. (a) Map of influencing factors ratings and (b) ratings of components of influencing factors and 1999 ratings in the Gulf of Mexico region.

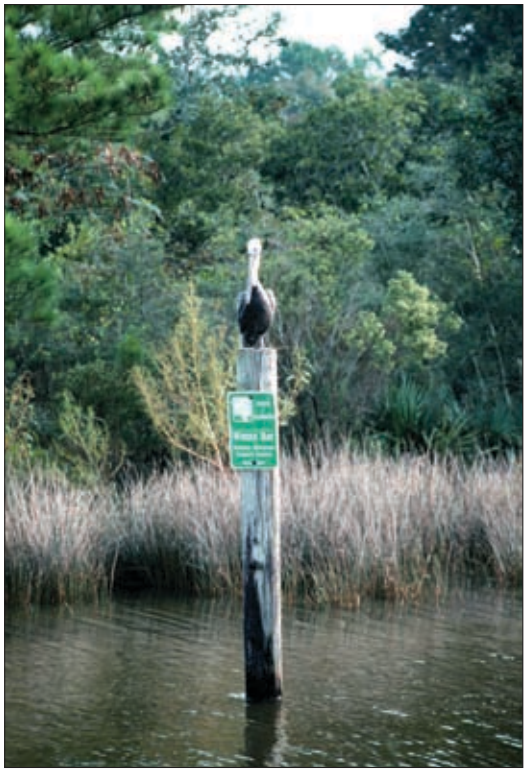


b) Influencing factors: comparisons

Estuary	2004 Influencing factors	2004 Susceptibility	2004 Nitrogen loads	1999 Influencing factors
1. Florida Bay	Insufficient data	Moderate	Insufficient data	Highly influenced
2. S. Ten Thousand Islands	Insufficient data	Highly influenced	Insufficient data	Highly influenced
3. N. Ten Thousand Islands	Insufficient data	Highly influenced	Insufficient data	Moderate
4. Rookery Bay	Insufficient data	Highly influenced	Insufficient data	Slight
5. Charlotte Harbor	Highly influenced	Highly influenced	Highly influenced	Highly influenced
6. Caloosahatchee River	Highly influenced	Moderate	Highly influenced	Highly influenced
7. Sarasota Bay	Insufficient data	Moderate	Insufficient data	Highly influenced
8. Tampa Bay	Slight	Moderate	Slight	Highly influenced
9. Suwannee River	Highly influenced	Moderate	Highly influenced	Slight
10. Apalachee Bay	Moderate	Moderate	Moderate	Slight
11. Apalachicola Bay	Highly influenced	Moderate	Highly influenced	Highly influenced
12. St. Andrew Bay	Insufficient data	Moderate	Insufficient data	Moderate
13. Choctawhatchee Bay	Insufficient data	Moderate	Insufficient data	Highly influenced
14. Pensacola Bay	Slight	Moderate	Slight	Highly influenced
15. Perdido Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
16. Mobile Bay	Highly influenced	Moderate	Highly influenced	Moderate
17. East Mississippi Sound	Insufficient data	Moderate	Insufficient data	Moderate
18. West Mississippi Sound	Highly influenced	Moderate	Highly influenced	Moderate
19. Lake Borgne	Insufficient data	Moderate	Insufficient data	Moderate
20. Lake Pontchartrain	Highly influenced	Moderate	Highly influenced	Highly influenced
21. Breton/Chandeleur Sounds	Insufficient data	Moderate	Insufficient data	Slight
22. Mississippi River	Slight	Slight	Highly influenced	Moderate
23. Barataria Bay	Highly influenced	Moderate	Highly influenced	Moderate
24. Terrebonne/Timbalier Bays	Highly influenced	Highly influenced	Moderate	Moderate
25. Atchafalaya/Vermilion Bays	Insufficient data	Slight	Insufficient data	Moderate
26. Mermentau Estuary	Insufficient data	Moderate	Insufficient data	Slight
27. Calcasieu Lake	Highly influenced	Moderate	Highly influenced	Highly influenced
28. Sabine Lake	Slight	Slight	Highly influenced	Slight
29. Galveston Bay	Highly influenced	Moderate	Highly influenced	Highly influenced
30. Brazos River	Insufficient data	Moderate	Insufficient data	Moderate
31. Matagorda Bay	Highly influenced	Highly influenced	Highly influenced	Highly influenced
32. San Antonio Bay	Insufficient data	Moderate	Insufficient data	Highly influenced
33. Aransas Bay	Insufficient data	Highly influenced	Insufficient data	Moderate
34. Corpus Christi Bay	Highly influenced	Highly influenced	Highly influenced	Highly influenced
35. Upper Laguna Madre	Highly influenced	Highly influenced	Highly influenced	Highly influenced
36. Baffin Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
37. Lower Laguna Madre	Highly influenced	Highly influenced	Highly influenced	Highly influenced
38. Mississippi/Atchafalaya Plume	Highly influenced	Moderate	Highly influenced	Highly influenced

Influencing factors
- Highly influenced
- Moderately influenced
- Slightly influenced
- Insufficient data

Susceptibility/nitrogen loads
- High
- Moderate
- Slight
- Insufficient data



National Oceanic and Atmospheric Administration

A Brown Pelican in Weeks Bay National Estuarine Research Reserve, Alabama.

Overall eutrophic condition

- This region had relatively few estuaries with a high overall eutrophic condition (OEC).
- There was a greater proportion of systems with a low to moderate overall eutrophic condition in this region compared to other regions.

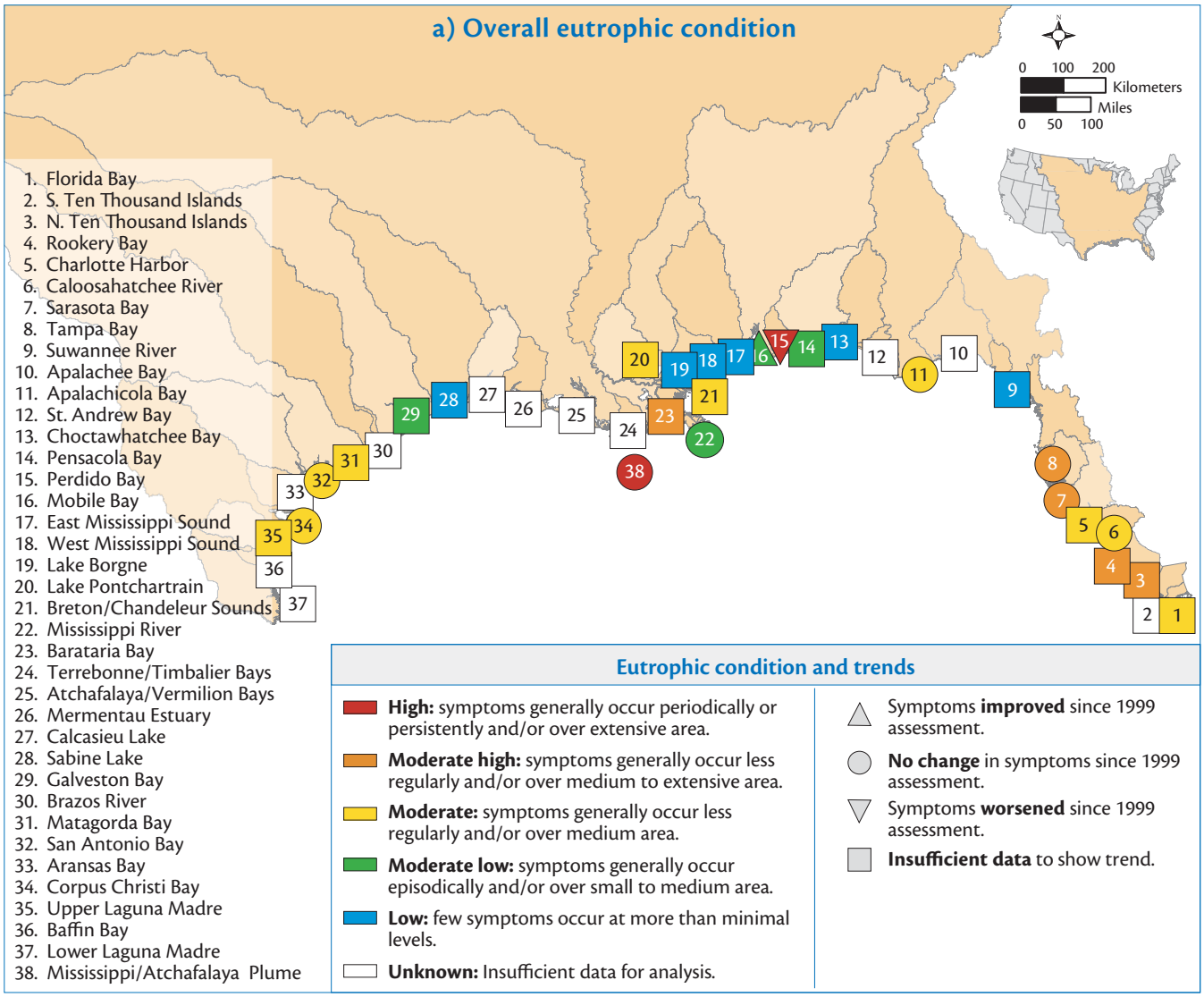
Most estuaries (20) in this region were characterized by moderate to low OEC, with relatively few estuaries receiving a high rating (Figure 4.15). Estuaries on the Florida peninsula tended to have moderate high OEC whereas estuaries assessed in Texas tended to have moderate conditions. In Mississippi and Alabama, a large proportion of estuaries had moderate low or low OEC (Figure 4.15).

Confidence in eutrophic condition ratings were mostly moderate and low. This is because many systems have data for only two symptoms and when data were available, there was a high degree of uncertainty. Furthermore, the overall confidence for the region was low due to the large number of systems that were not evaluated. The need for more data prevented definitive or complete characterization of this region.

Eutrophic symptom expressions

For systems where data were available, most symptoms show low and moderate level expressions, with the exception of chlorophyll *a*, for which 17 systems had high level conditions and five had moderate level conditions. The other primary symptom, macroalgae, was observed at high levels in

Figure 4.15. a) Map of overall eutrophic condition (OEC) and (b) the combination of individual eutrophic symptoms which constitute OEC ratings in the Gulf of Mexico region.



b) Overall eutrophic condition & eutrophic symptoms

Estuary	Overall eutrophic condition	Overall confidence expression	Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/ toxic blooms	SAV
1. Florida Bay	Moderate	*	Worsened	Insufficient data	Improved	Insufficient data	Insufficient data
2. S. Ten Thousand Islands	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
3. N. Ten Thousand Islands	Moderate high	*	Worsened	Insufficient data	No change	Insufficient data	Insufficient data
4. Rookery Bay	Moderate high	*	Worsened	Insufficient data	Worsened	Insufficient data	Insufficient data
5. Charlotte Harbor	Moderate	**	High	Worsened	Low	Low	Low
6. Caloosahatchee River	Moderate	**	High	Worsened	Low	Low	Low
7. Sarasota Bay	Moderate high	**	Worsened	Worsened	Improved	Moderate	Low
8. Tampa Bay	Moderate high	**	High	Worsened	Worsened	Moderate	Low
9. Suwannee River	Low[a]	**	Improved	Improved	No change	Low	Low
10. Apalachee Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
11. Apalachicola Bay	Moderate	**	Moderate	No change	Improved	Moderate	Low
12. St. Andrew Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
13. Choctawhatchee Bay	Low	*	Improved	Insufficient data	Improved	Insufficient data	Insufficient data
14. Pensacola Bay	Moderate low	*	Moderate	Insufficient data	Improved	Insufficient data	Insufficient data
15. Perdido Bay	Worsened	**	Improved	Moderate	Worsened	Low	Low
16. Mobile Bay	Improved	*	Moderate	No change	Improved	Improved	Insufficient data
17. East Mississippi Sound	Low	*	Improved	Insufficient data	Improved	Insufficient data	Insufficient data
18. West Mississippi Sound	Low	*	Improved	Insufficient data	No change	Insufficient data	Insufficient data
19. Lake Borgne	Low	*	Low	Insufficient data	No change	Insufficient data	Insufficient data
20. Lake Pontchartrain	Moderate	*	High	Moderate	No change	Improved	Insufficient data
21. Breton/Chandeleur Sounds	Moderate	*	High	Insufficient data	Insufficient data	No change	Insufficient data
22. Mississippi River	Moderate low	*	Moderate	Insufficient data	No change	Insufficient data	Insufficient data
23. Barataria Bay	Moderate high	*	High	Insufficient data	Insufficient data	Worsened	Insufficient data
24. Terrebonne/Timbalier Bays	Insufficient data	*	Insufficient data	Insufficient data	No change	Insufficient data	Insufficient data
25. Atchafalaya/Vermilion Bays	Insufficient data	*	Insufficient data	Insufficient data	No change	Insufficient data	Insufficient data
26. Mermentau Estuary	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
27. Calcasieu Lake	Insufficient data	*	Insufficient data	Insufficient data	Improved	Insufficient data	Insufficient data
28. Sabine Lake	Low	**	Improved	No change	No change	No change	No change
29. Galveston Bay	Moderate low	**	Worsened	No change	No change	No change	Improved
30. Brazos River	Insufficient data	*	Worsened	Insufficient data	Insufficient data	Insufficient data	Insufficient data
31. Matagorda Bay	Moderate	*	Worsened	No change	No change	No change	No change
32. San Antonio Bay	Moderate	*	Worsened	Insufficient data	No change	Insufficient data	Insufficient data
33. Aransas Bay	Insufficient data	*	Worsened	Insufficient data	Insufficient data	Insufficient data	Insufficient data
34. Corpus Christi Bay	Moderate	*	High	High	Insufficient data	Improved	Insufficient data
35. Upper Laguna Madre	Moderate	*	Improved	Insufficient data	Insufficient data	Improved	Insufficient data
36. Baffin Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
37. Lower Laguna Madre	Insufficient data	*	Improved	Insufficient data	Insufficient data	Insufficient data	Insufficient data
38. Mississippi/Atchafalaya Plume	High	*	High	No change	High	Insufficient data	No change

Eutrophic condition in 2004

- High
- Moderate high
- Moderate
- Moderate low
- Low
- Insufficient data

Overall confidence expression in 2004

- *** High
- ** Moderate
- * Low

Change in eutrophic condition since 1999 assessment

- Improved
- No change
- Worsened
- Insufficient data

[a] For Suwannee River, variability in rainfall precludes determination of change.

only three systems and moderate in four. However, there was a paucity of data for this indicator, with 24 systems having unknown levels. The systems with high chlorophyll *a* expression were mostly located in Florida and Texas. Of the secondary symptoms, significant dissolved oxygen problems were reported in only two systems (Perdido Bay and the Mississippi Plume). All 11 assessed systems had a low level loss of submerged aquatic vegetation. Five estuaries had moderate nuisance/toxic bloom expressions and 11 were rated as low (Figure 4.15).

Changes in eutrophic condition since the 1990s

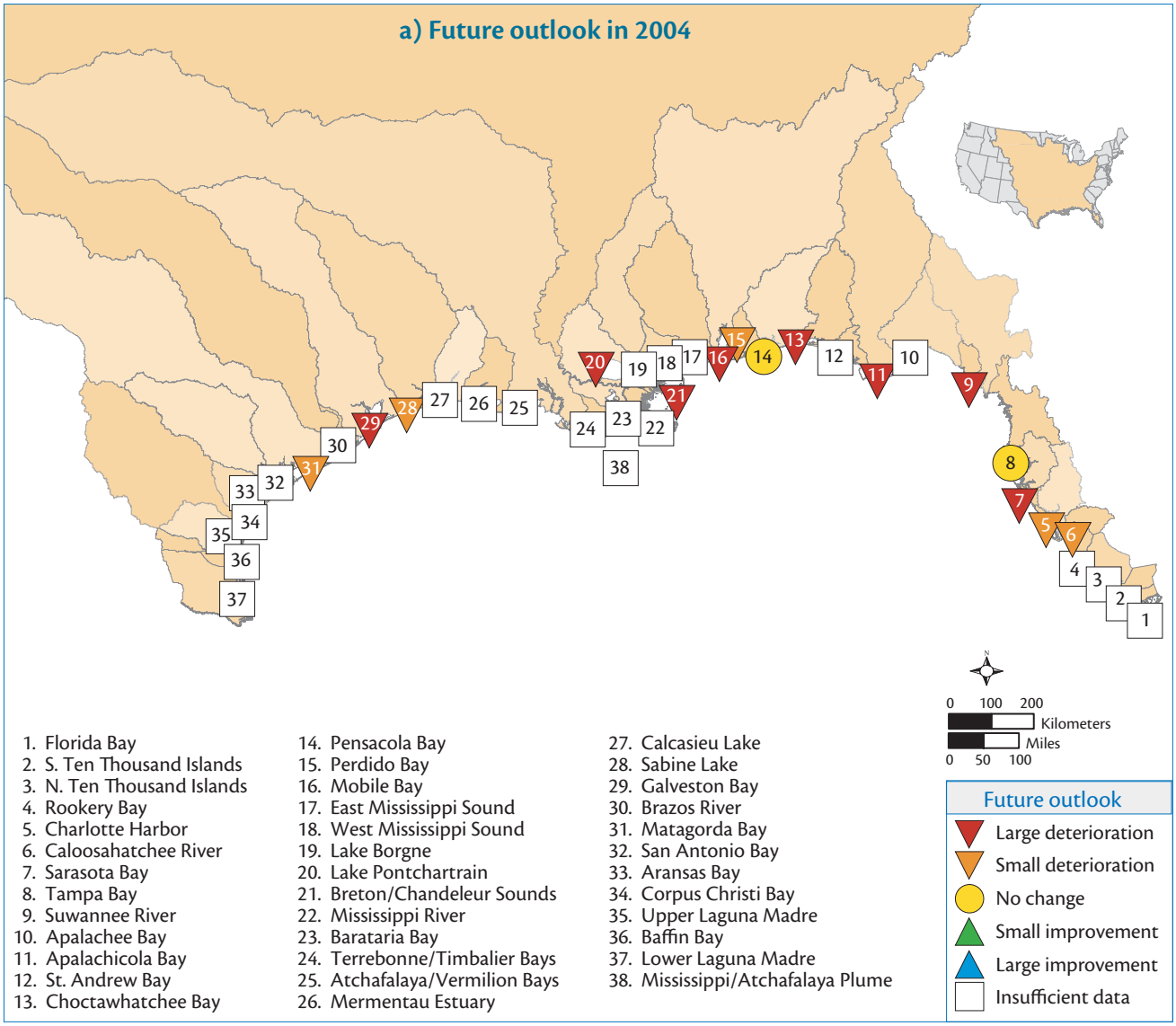
Since the 1999 assessment, conditions have become worse in one system and have improved in another. Worsening conditions in Perdido Bay are accounted for by a decrease in dissolved oxygen. In Mobile Bay, improvements in dissolved oxygen and nuisance/toxic blooms were noted. For 16 systems, assessments were made in both 1999 and 2004. However, a trend analysis was not possible because the indicators used were not comparable between assessments (Figure 4.15).

Future outlook

- Future outlook was bleak, with conditions expected to worsen in all but two of the assessed systems.
- Future outlook has not changed since the last assessment (early 1990s).

Of the 38 Gulf region estuaries studied, 13 were predicted to develop worsening conditions, eight to a high degree and five to a lesser degree (Figure 4.16). For Tampa Bay, which has seen noted regrowth

Figure 4.16. (a) Map of Gulf of Mexico future outlook in 2004 and (b) in comparison with the 1999 future outlook.



b) Future outlook comparisons

Estuary	Future outlook in 2004	Actual change in eutrophic condition (1999 - 2004)	Future outlook in 1999
1. Florida Bay	Insufficient data	Insufficient data	Small improvement
2. S. Ten Thousand Islands	Insufficient data	Insufficient data	Small deterioration
3. N. Ten Thousand Islands	Insufficient data	Insufficient data	Small deterioration
4. Rookery Bay	Insufficient data	Insufficient data	No change
5. Charlotte Harbor	Small deterioration	Insufficient data	Small deterioration
6. Caloosahatchee River	Small deterioration	No change	Small deterioration
7. Sarasota Bay	Large deterioration	No change	Small deterioration
8. Tampa Bay	No change	No change	No change
9. Suwannee River	Large deterioration	Insufficient data	Small deterioration
10. Apalachee Bay	Insufficient data	Insufficient data	Small deterioration
11. Apalachicola Bay	Large deterioration	No change	Small deterioration
12. St. Andrew Bay	Insufficient data	Insufficient data	Small deterioration
13. Choctawhatchee Bay	Large deterioration	Insufficient data	Small deterioration
14. Pensacola Bay	No change	Insufficient data	Small deterioration
15. Perdido Bay	Small deterioration	Worsened	Small deterioration
16. Mobile Bay	Large deterioration	Improved	No change
17. East Mississippi Sound	Insufficient data	Insufficient data	No change
18. West Mississippi Sound	Insufficient data	Insufficient data	No change
19. Lake Borgne	Insufficient data	Insufficient data	No change
20. Lake Pontchartrain	Large deterioration	Insufficient data	Large deterioration
21. Breton/Chandeleur Sounds	Large deterioration	Insufficient data	Small improvement
22. Mississippi River	Insufficient data	No change	No change
23. Barataria Bay	Insufficient data	Insufficient data	No change
24. Terrebonne/Timbalier Bays	Insufficient data	Insufficient data	Small deterioration
25. Atchafalaya/Vermilion Bays	Insufficient data	Insufficient data	No change
26. Mermentau Estuary	Insufficient data	Insufficient data	Small improvement
27. Calcasieu Lake	Insufficient data	Insufficient data	Small deterioration
28. Sabine Lake	Small deterioration	Insufficient data	No change
29. Galveston Bay	Large deterioration	Insufficient data	Small deterioration
30. Brazos River	Insufficient data	Insufficient data	No change
31. Matagorda Bay	Small deterioration	Insufficient data	Small deterioration
32. San Antonio Bay	Insufficient data	No change	Small deterioration
33. Aransas Bay	Insufficient data	Insufficient data	No change
34. Corpus Christi Bay	Insufficient data	No change	Large deterioration
35. Upper Laguna Madre	Insufficient data	Insufficient data	Large deterioration
36. Baffin Bay	Insufficient data	Insufficient data	Large deterioration
37. Lower Laguna Madre	Insufficient data	Insufficient data	Large deterioration
38. Mississippi/Atchafalaya Plume	Insufficient data	No change	Large deterioration

Future outlook

- Large deterioration
- Small deterioration
- No change
- Small improvement
- Large improvement
- Insufficient data

Change in eutrophic condition since 1999 assessment

- Improved
- No change
- Worsened
- Insufficient data

and gains in spatial coverage of submerged aquatic vegetation in the past, the conditions are expected to remain the same due to management strategies to compensate for expected increases in nutrient loads from population growth. For Charlotte Harbor, the prediction of worsening conditions is due to land use conversions from low to highly intensive usage (e.g., rangeland to row crops or urban). Other expected factors potentially influencing future changes in this region are urban runoff, wastewater treatment, industry, atmospheric deposition, animal operations (Sabine Lake), and agriculture (crops and rangeland or pasture).

There were no systems for which conditions were expected to improve. Future conditions for 23 systems are unknown, making it difficult to draw conclusions about future conditions in the region. What can be noted is that for many of the systems expected to worsen, present conditions are moderate or low and susceptibility is moderate. These systems are at risk of future degradation and should be a priority for management.

The future outlook is the same as it was in the early 1990s, with worsening conditions predicted in all systems for which data were available. For the ten systems where an evaluation was possible, predictions have been realized in only three systems as of this interim date (predictions are for year 2020). This result may stem from the fact that these expected changes are for the year 2020. While some areas demonstrate condition changes sooner than others, the accuracy of these particular predictions should be addressed in 2020, or predictions should be made for a shorter time scale.

Assessment of Estuarine Trophic Status (ASSETS)

An ASSETS rating which combines influencing factors, overall eutrophic condition, and future outlook could be made for ten of the 38 systems. Two systems were rated as good (Pensacola Bay, Sabine Lake), two systems were rated as moderate (Mobile Bay and Galveston Bay), and six as poor (Charlotte Harbor, Apalachicola Bay, Caloosahatchee River, Matagorda Bay, Tampa Bay, and Lake Ponchartrain).

Impaired uses

- Twelve systems had impacts to living resources, seven either moderate or high.
- The most noted causes of impacts to living resources were wastewater treatment, urban runoff, onsite septic tanks, and agriculture.
- Only six systems had human use impairments (primarily shellfish, commercial and recreational fishing, swimming, and aesthetics).
- Living resources were most impaired in systems with higher level overall eutrophic conditions.

Living resources were reported as being impaired in twelve systems, with considerable impacts noted in two systems (Sarasota Bay, Perdido Bay), moderate in five systems (Charlotte Harbor, Choctawhatchee Bay, Lake Ponchartrain, Barataria Bay, Mississippi/Atchafalaya River Plume), and slight or no impacts in an additional six systems (Apalachicola Bay, Pensacola Bay, Breton/Chandeleur Sound, Sabine Lake, Matagorda Bay, Suwannee River). The causes of these impairments were primarily wastewater treatment, urban runoff, and onsite septic tanks. Industry, atmospheric deposition, combined sewer overflows, and agriculture were also noted. For Charlotte Harbor, moderate impacts to living resources are caused by land use conversions from low to more intensive usage (e.g., rangeland to row crops or urban) and for Breton/Chandeleur Sounds, recent river diversion has resulted in observations of chlorophyll *a* > 50 μg l^{-1}. In this region, the level of impact to living resources corresponds to the level of eutrophic conditions.

Peter Doering, South Florida Water Management District

A cyanobacteria bloom in Caloosahatchee River, Florida.

Peter Doering, South Florida Water Management District

Dead fish from a red tide in the Pine Island Sound region of Charlotte Harbor, Florida.

Use impairments were reported in 6 systems (Caloosahatchee River, Sarasota Bay, Apalachicola Bay, Choctawhatchee Bay, Pensacola Bay, Perdido Bay), while impairments to the remaining 32 estuaries are unknown. Shellfish, commercial and recreational fishing, swimming, and aesthetics were the most often noted impairments. However, tourism, boating, fish consumption, and impacts to the municipal water supply (Caloosahatchee River), were also noted. Impairments were most often observed in systems with moderate to high eutrophic conditions but were also reported in systems with low ratings.

Potential management concerns

The most often noted sources of nutrients were urban runoff, wastewater treatment, atmospheric deposition, and onsite septic tanks (Florida systems). The nutrient loads from agricultural practices in this region also continue to be a major management concern. Both point and non-point nutrient sources are expected to cause worsening conditions in the future and so should be targeted for management (see "Monitoring," below). The systems that are moderately or highly susceptible and at present show moderate eutrophic conditions, use impairments, and impacts to living resources, should be a priority for management.

U.S. Department of Transportation, Maritime Administration

Tanker ships in the Houston Ship Canal. Monitoring in the canal suggests improvements in water quality.

Data gaps and research needs

Monitoring

There are many data gaps for many systems in this region. Routine monitoring should be a priority so that water quality can be evaluated and trends tracked through time. Load estimates for this region are also scarce. There are examples of both improving (e.g., Mobile Bay) as well as degrading (e.g., Perdido Bay) conditions. There are also systems without overall eutrophic change, which have decreasing point sources but increasing non-point sources, which should be targeted for monitoring.

Research

Over half of the systems in this region did not have load estimates, which are critical for determining the causes of observed living resource and use impairments. They are also needed for prescribing best management practices in order to improve conditions. It is recommended that research focus on the development of loading estimates for the region. Furthermore, the relative roles of nitrogen and phosphorus in the development of eutrophic conditions should be explored. Given that increased circulation to these systems may alleviate eutrophication to some degree, research should also include inlet circulation and approaches to inlet management.

Management

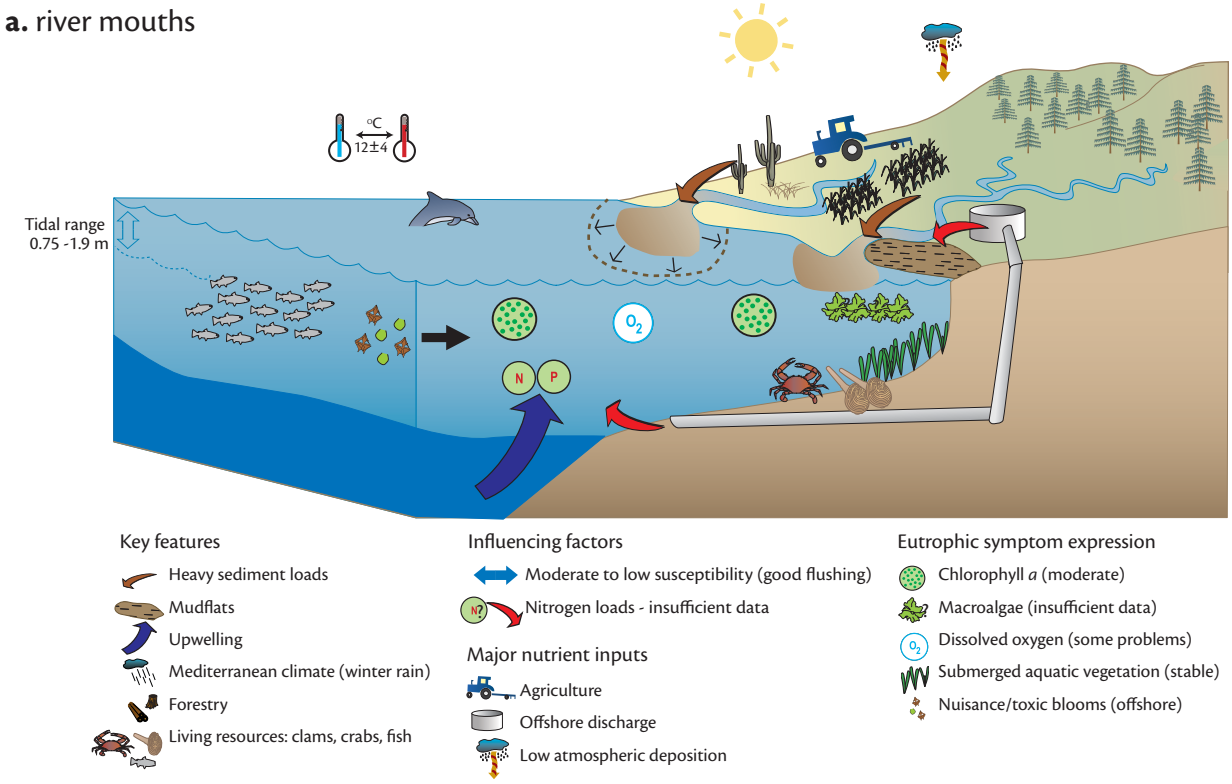
Major management foci should include improvements to wastewater treatment, onsite septic tanks, and re-designs of combined sewer overflow. Reductions of urban and industry runoff and atmospheric deposition were also named as targets for management. Though management action should focus on identifying and managing nutrient sources, there is also a strong need to close the data gaps which may affect these decisions. Efforts should be allocated toward the improvement and organization of routine monitoring systems.

PACIFIC COAST REGION

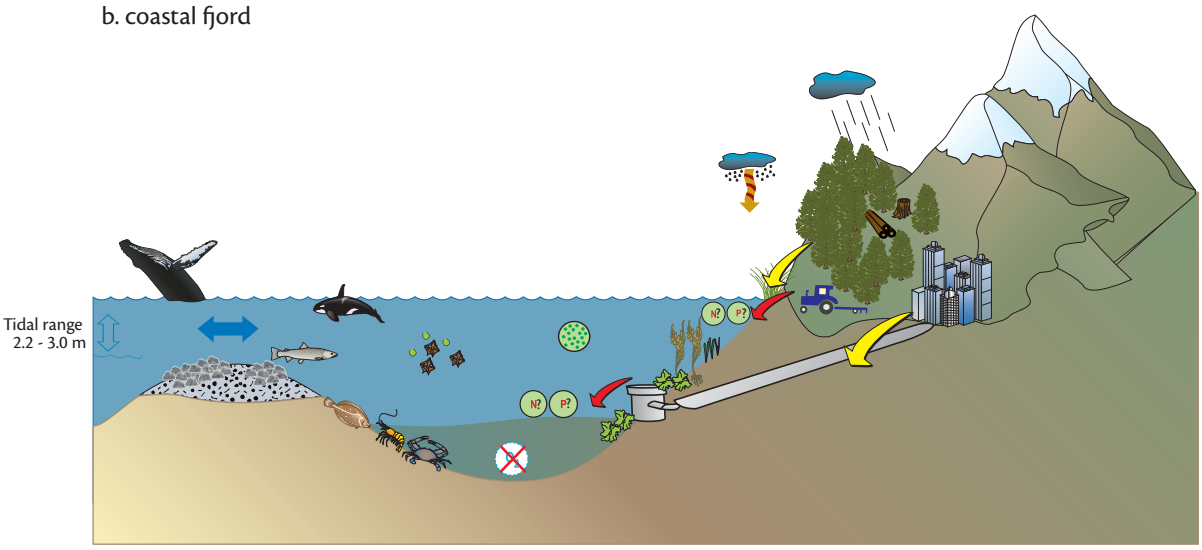
- Very few estuaries have nutrient load data available.
- Most estuaries with reported problems were located in Washington State and central California, with chlorophyll *a* and dissolved oxygen being the major eutrophic symptoms.
- Only one system was rated with a high overall eutrophic condition.

The Pacific Coast region includes 39 estuaries, encompassing more than 7,113 km² of water surface area. The region consists of a relatively straight and uninterrupted shoreline with rocky shores, sandy beaches, and occasional river outlets (Figure 4.17a-c). Limited areas of flat, lowland environments support estuaries, bays, and lagoons. The river mouth estuaries are found in Oregon (Figure 4.17a), the fjord systems in northern Washington State (Figure 4.17b), and the lagoons are mostly found in California (Figure 4.17c). The water bodies along the Pacific coast are typically small and separated by large distances. Estuarine circulation patterns are dominated mainly by seasonal freshwater inflow in southern California and by freshwater inflow and tides in the larger estuaries of central California and Washington. Tidal range is variable (0.75–3.0 m), with higher averages found in the fjord systems (2.4 m). Likewise, the depth range is large (0.2–96m), with higher average depths found in the Washington State fjord systems (66 m). Precipitation in the northern part of the region (1.7 m yr^{-1}) is more than

Figure 4.17. Conceptual diagram of Pacific Coast key features, major nutrient sources, and resulting symptoms.



b. coastal fjord



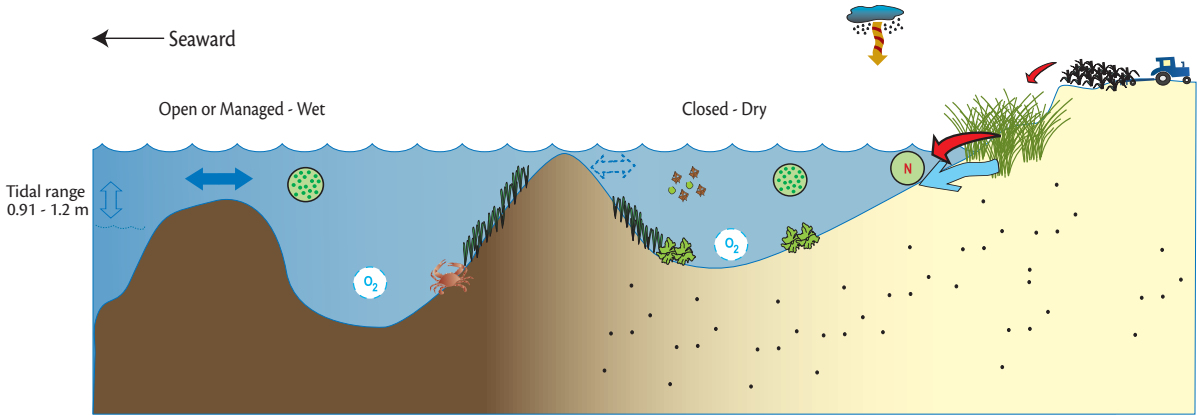
Key features
- Rocky
- Mediterranean climate
- Fringing marsh and seagrass
- Kelp beds
- Forestry
- Living resources: crabs, fish

Influencing factors
- Moderate to low susceptibility (good flushing)
- Nitrogen loads - insufficient data

Major nutrient sources
- Agriculture
- Urban; offshore discharges
- Stormwater
- Low atmospheric deposition

Eutrophic symptom expression
- Chlorophyll *a* (high)
- Macroalgae (moderate)
- Dissolved oxygen (moderate to low expression)
- Submerged aquatic vegetation (stable or nonexistent)
- Nuisance/toxic blooms (low)

c. lagoons



Key features
- Freshwater inflow
- Muddy and sandy bottoms
- Small marsh
- Seagrass beds
- Living resources: crabs

Influencing factors
- Moderate to low susceptibility (poor flushing)
- Hign nitrogen loads

Major nutrient inputs
- Agriculture
- Low atmospheric deposition

Eutrophic symptom expression
- Chlorophyll *a* (high)
- Macroalgae (mostly low)
- Dissolved oxygen (some problems)
- Submerged aquatic vegetation (stable)
- Nuisance/toxic blooms (moderate)

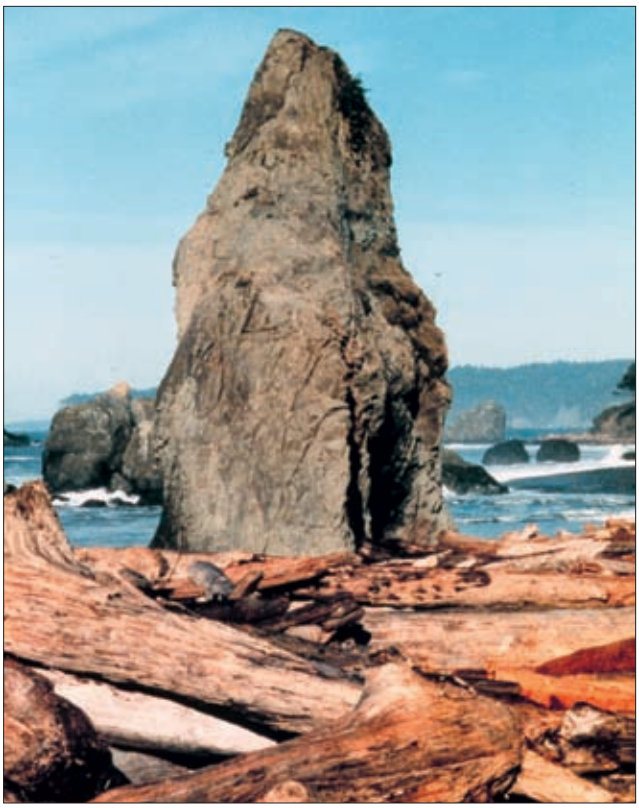
twice that recorded in California (0.57 m yr^{-1}). Air temperature and frost days show a similar pattern in Washington and Oregon, with average annual temperatures of 10°C and 79 frost days per year, while California averages annual temperatures of 15°C and 35 frost days per year. Some of the major population centers include Los Angeles, San Diego, San Francisco, and Seattle. Average population densities are also distinctly different in the northern and southern part of this region, with an average of 106 people per km^2 in California compared to 10 people per square kilometer in Washington and Oregon. The regional average population density is 33 people per km^2. Forestry, agriculture, and industry are the dominant land uses in the region (Figure 4.17a-c).

Influencing factors

- There were insufficient data to make conclusions about influencing factors in this region.

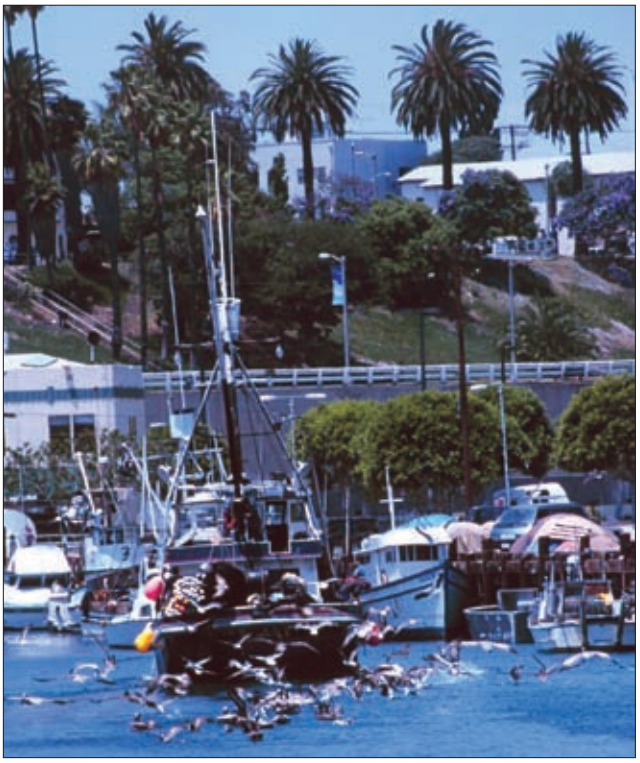
There were very little nutrient loading data for the Pacific Coast region; only four systems had load estimates (Figure 4.18). The load to Newport Bay, San Francisco Bay South, and Hood Canal are all classified as high. The susceptibility of systems in this region is varied, with the lagoonal systems in California characterized mostly by high susceptibility, due to low dilution and flushing capability. Alternatively, the river mouth estuaries in Oregon and Washington state are moderately susceptible on account of high flushing but low dilution capability. The fjord type systems in Washington State are in general less susceptible than other systems, due to high dilution and moderate flushing capability. These combinations lead to high values for influencing factors in Newport Bay and Hood Canal and moderate low in San Francisco Bay North.

It is not possible to conclude anything about influencing factors in this region, due to a lack of data. However, it is expected that the human influence on the expression of eutrophic symptoms is very high. Southern California systems in particular have high human influence because they are among the top ten U.S. estuaries with respect to watershed population density. Tijuana Estuary is also notable because three-quarters of the watershed is located in Mexico, making management an international challenge.



National Oceanic and Atmospheric Administration

Pinnacle rocks and weather-beaten logs are characteristic of water bodies in Oregon and Washington.

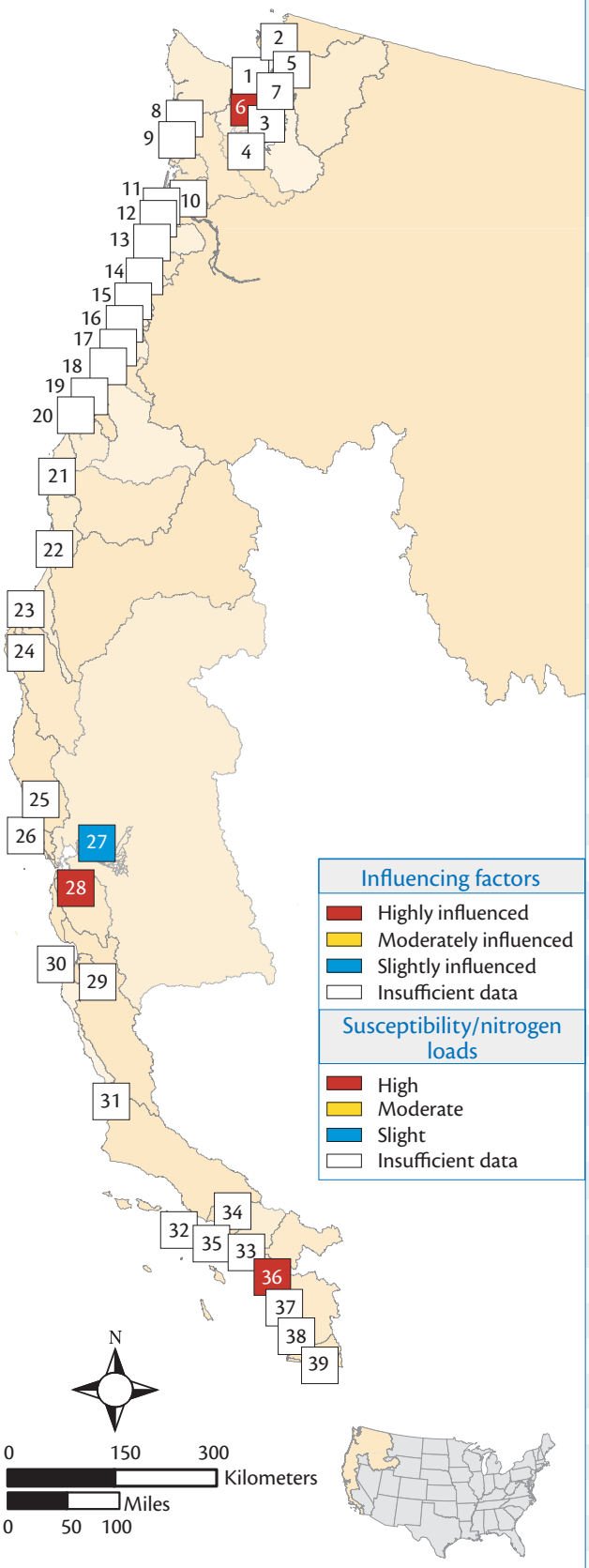


National Oceanic and Atmospheric Administration

Pelicans following a fishing boat in San Pedro Bay, California. California estuaries are typically lagoons.

Figure 4.18. Map of influencing factors ratings, ratings of components of influencing factors, and 1999 ratings in the Pacific region.

Influencing factors: 2004



Influencing factors: comparisons

Estuary	2004 Influencing factors	2004 Susceptibility	2004 Nitrogen loads	1999 Influencing factors
1. Sequim/Discovery Bays	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
2. Bellingham/Padilla/Samish Bays	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
3. Port Orchard System	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
4. South Puget Sound	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
5. Skagit Bay/Whidbey Basin	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
6. Hood Canal	Highly influenced	Highly influenced	Highly influenced	Highly influenced
7. Puget Sound	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
8. Grays Harbor	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
9. Willapa Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
10. Columbia River	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
11. Nehalem River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
12. Tillamook Bay	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
13. Netarts Bay	Insufficient data	Highly influenced	Insufficient data	Moderately influenced
14. Siletz Bay	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
15. Yaquina Bay	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
16. Alsea River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
17. Siuslaw River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
18. Umpqua River	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
19. Coos Bay	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
20. Coquille River	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
21. Rogue River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
22. Klamath River	Insufficient data	Moderately influenced	Insufficient data	Slightly influenced
23. Humboldt Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
24. Eel River	Insufficient data	Moderately influenced	Insufficient data	Moderately influenced
25. Tomales Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
26. Drakes Estero	Insufficient data	Slightly influenced	Insufficient data	Highly influenced
27. San Francisco Bay North	Slightly influenced	Slightly influenced	Highly influenced	Slightly influenced
28. San Francisco Bay South	Highly influenced	Moderately influenced	Highly influenced	Highly influenced
29. Elkhorn Slough	Insufficient data	Highly influenced	Insufficient data	Highly influenced
30. Monterey Bay	Insufficient data	Slightly influenced	Insufficient data	Slightly influenced
31. Morro Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
32. Santa Monica Bay	Insufficient data	Moderately influenced	Insufficient data	Highly influenced
33. Anaheim Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
34. Alamitos Bays	Insufficient data	Highly influenced	Insufficient data	Insufficient data
35. San Pedro Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
36. Newport Bay	Highly influenced	Highly influenced	Highly influenced	Highly influenced
37. Mission Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
38. San Diego Bay	Insufficient data	Highly influenced	Insufficient data	Highly influenced
39. Tijuana Estuary	Insufficient data	Highly influenced	Insufficient data	Highly influenced

Overall eutrophic condition

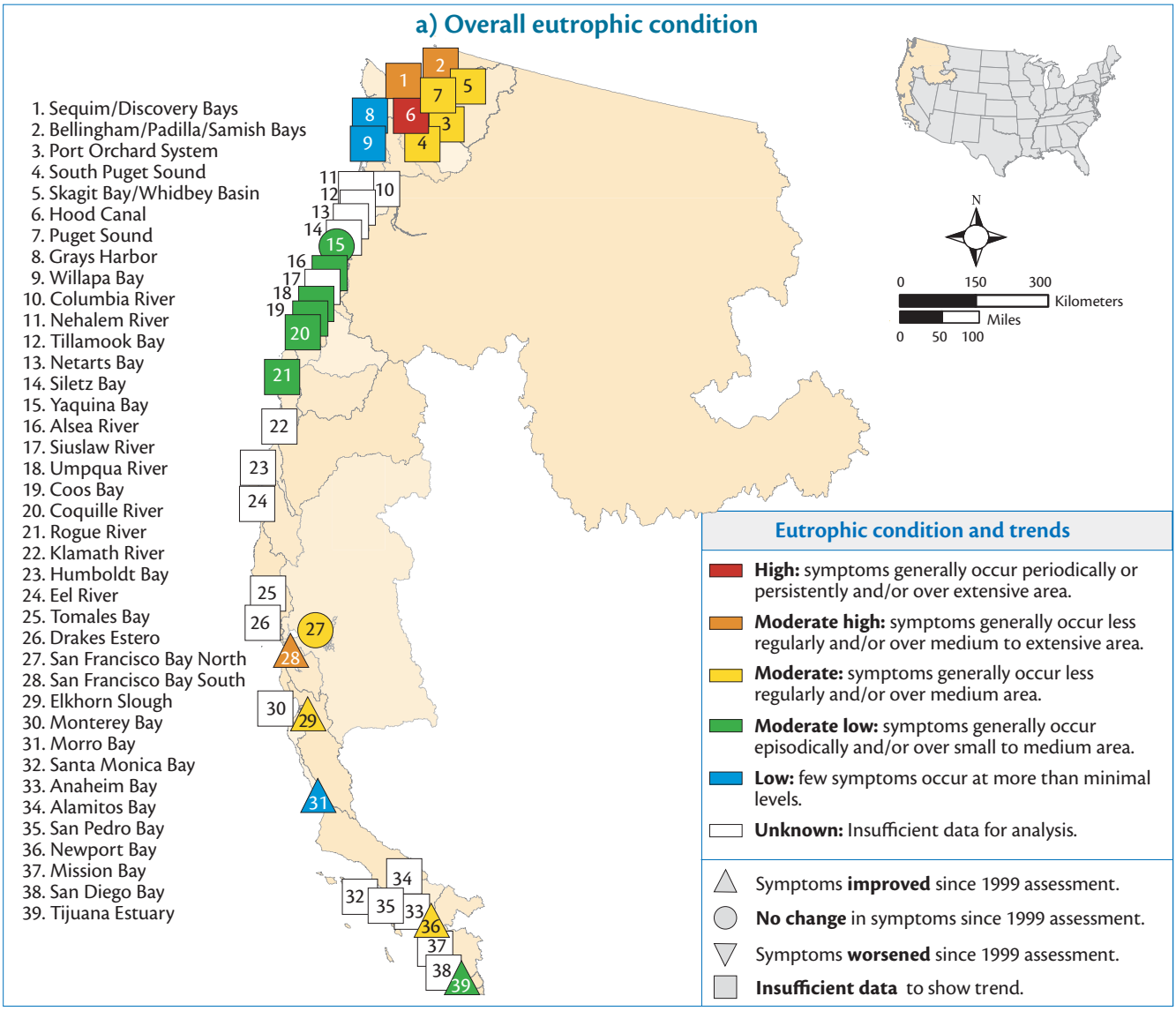
- Only one system had an overall eutrophic condition (OEC) rating of high.
- Most of the eutrophic estuaries in this region are located in Washington State and central California, with chlorophyll *a* and dissolved oxygen as the major symptom expressions.

Due to a lack of data, only half of the systems in this region were assigned an overall eutrophic condition rating (OEC). Of the assessed systems, those with moderate high to high OEC were located in the Puget Sound and San Francisco areas (Figure 4.19). In contrast, estuaries in the Oregon region all had moderate low overall eutrophic condition ratings.

Tim Carruthers, University of Maryland Center for Environmental Science

Estuarine mud flat at Morro Bay, California, showing extensive macroalgae growth.

Figure 4.19. (a) Map of overall eutrophic condition (OEC) and (b) the combination of individual eutrophic symptoms which constitute OEC ratings in the Pacific Coast.



b) Overall eutrophic condition & eutrophic symptoms

Estuary	Overall eutrophic condition	Overall confidence expression	Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/toxic blooms	SAV
1. Sequim/Discovery Bays	Moderate high	**	High	Low	Moderate high	Moderate	Low
2. Bellingham/Padilla/Samish Bays	Moderate high	**	High	Moderate	Moderate high	Low	Low
3. Port Orchard System	Moderate	**	High	Moderate	Moderate	Low	Low
4. South Puget Sound	Moderate	*	High	Moderate	Moderate	Low	Low
5. Skagit Bay/Whidbey Basin	Moderate	**	High	Moderate	Moderate high	Low	Low
6. Hood Canal	High	**	High	Moderate	High	Low	Low
7. Puget Sound	Moderate	**	High	Moderate	Moderate	Low	Moderate
8. Grays Harbor	Low	**	Low	Low	Moderate	Low	Low
9. Willapa Bay	Low	*	Low	Low	Moderate	Low	Low
10. Columbia River	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
11-13 (Nehalem River, Tillamook Bay, and Netarts Bay are unknown for all indicators)							
14. Siletz Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
15. Yaquina Bay	Moderate low	*	Moderate	Insufficient data	Low	Insufficient data	Insufficient data
16. Alsea River	Moderate low	*	Moderate	Insufficient data	Low	Insufficient data	Insufficient data
17. Siuslaw River	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
18. Umpqua River	Moderate low	*	Moderate high	Insufficient data	Low	Insufficient data	Insufficient data
19. Coos Bay	Moderate low	*	Moderate	Insufficient data	Low	Insufficient data	Insufficient data
20. Coquille River	Moderate low	*	Moderate high	Insufficient data	Low	Insufficient data	Insufficient data
21. Rogue River	Moderate low	*	Moderate	Insufficient data	Low	Insufficient data	Insufficient data
22. Klamath River	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
23-25 (Humboldt Bay, Eel River, and Tomales Bay are unknown for all indicators)							
26. Drakes Estero	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
27. San Francisco Bay North	Moderate	**	High	Low	Low	Moderate	Moderate high
28. San Francisco Bay South	Moderate high	*	High	Low	Low	Moderate high	Moderate high
29. Elkhorn Slough	Moderate	**	Moderate high	High	Moderate high	Insufficient data	Low
30. Monterey Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
31. Morro Bay	Moderate high	**	Insufficient data	Moderate high	Low	Moderate high	Moderate high
32. Santa Monica Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Moderate	Insufficient data
33. Anaheim Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
34. Alamitos Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
35. San Pedro Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
36. Newport Bay	Moderate	*	Insufficient data	High	Moderate high	Insufficient data	Moderate high
37. Mission Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
38. San Diego Bay	Insufficient data	*	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
39. Tijuana Estuary	Moderate high	**	Moderate	Moderate	Moderate high	Low	Low

Eutrophic condition in 2004

- High
- Moderate high
- Moderate
- Moderate low
- Low
- Insufficient data

Overall confidence expression in 2004

- *** High
- ** Moderate
- * Low

Change in eutrophic condition since 1999 assessment

- Improved
- No change
- Worsened
- Insufficient data

Shih-Nan Chen, University of Maryland Center for Environmental Science

An algal bloom in the Columbia River near Astoria, Oregon.

In general, the symptoms contributing most to the higher level eutrophic conditions were elevated levels of chlorophyll *a* and dissolved oxygen problems. The confidence in the assessment of individual systems and overall confidence in the region was mostly low due to low availability of data (Figure 4.19).

Eutrophic symptom expressions

Of the primary symptoms, chlorophyll *a* was expressed at high levels in nine systems, and at moderate levels in seven systems. Macroalgae data were reported for 15 systems, with a symptom expression of high in two, moderate in seven, and low in six estuaries. Of the secondary symptoms, dissolved oxygen was high in one system, moderate in three, and low or no problem in 17 systems. However, in a few systems (Bellingham/Padilla/Samish and Sequim/Discovery Bays), these ratings may not be effective at representing dissolved oxygen conditions. These particular systems are influenced by inflows of upwelled oceanic water which is low in dissolved oxygen, and therefore contributes to dissolved oxygen problems which might otherwise be attributed to human influence. Nuisance/toxic blooms were reported for only five systems, with moderate level problems observed in only two systems. Loss of submerged aquatic vegetation was reported as low or no problem for nine systems, while the remaining 30 systems were unknown. Part of the reason for the paucity of data for the Oregon systems is that other issues, such as contaminants, are considered more of a pressing concern than eutrophication.

Changes in eutrophic condition since the 1990s

Comparison of data with the 1999 assessment shows that five systems have improved, mostly due to improved chlorophyll *a* and dissolved oxygen conditions. Two systems have remained the same since the 1999 assessment but for most systems a change could not be determined (Figure 4.19). It is difficult to draw any conclusions about patterns in this region due to a lack of data for recent conditions and thus trends analysis.

Future outlook

- There were insufficient data to make any conclusions about future outlook.
- Of the eight systems for which future outlook was reported, most are expected to worsen.

Five estuaries in the Pacific Coast region were predicted to develop worsening conditions in the future, while three were predicted to improve. There was no information for 31 systems.

The reported reasons for worsening conditions were onsite septic tanks, urban runoff, and forestry (the latter in Hood Canal only). The potential reasons for future improvement were noted as changes to industry, urban runoff (Newport Bay), and agriculture. Expected improvements in Santa Monica Bay are attributed to the Total Maximum Daily Load (TMDL) for Malibu Creek, which is expected to decrease the nutrient loads. However, these may be offset by increased atmospheric inputs. Consequently, the decrease is expected to be small.

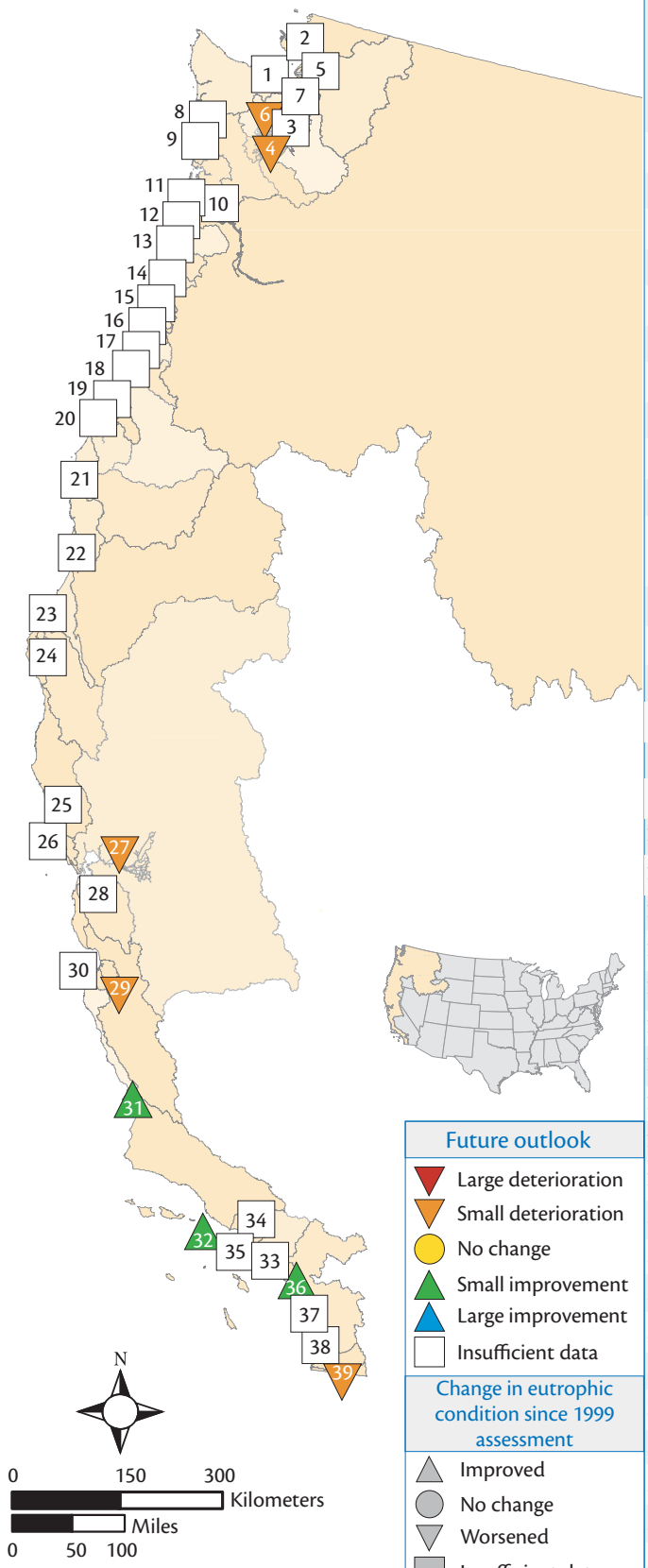
There is insufficient data to make overall conclusions about future outlook. Of the seven systems for which a comparison could be made, only one was consistent with future outlook predictions from 1999 (San Francisco Bay North). This result may stem from the fact that these expected changes are for the year 2020. While some areas demonstrate condition changes sooner than others, the accuracy of these particular predictions should be addressed in 2020, or predictions should be made for a shorter time scale.

Assessment of Estuarine Trophic Status (ASSETS)

Only three systems received an ASSETS rating, which combines influencing factors, overall eutrophic condition, and future outlook. Hood Canal was characterized as bad, and both Newport and San Francisco Bay as moderate.

Figure 4.20. Future outlook in 2004 and comparison with 1999 future outlook.

Future outlook in 2004



Future outlook comparisons

Estuary	Future outlook in 2004	Actual change in eutrophic condition (1999 - 2004)	Future outlook in 1999
1. Sequim/Discovery Bays	Insufficient data	Insufficient data	Small deterioration
2. Bellingham/Padilla/Samish Bays	Insufficient data	Insufficient data	Small deterioration
3. Port Orchard System	Insufficient data	Insufficient data	Small deterioration
4. South Puget Sound	Small deterioration	Insufficient data	Large deterioration
5. Skagit Bay/Whidbey Basin	Insufficient data	Insufficient data	Small deterioration
6. Hood Canal	Small deterioration	Insufficient data	Large deterioration
7. Puget Sound	Insufficient data	Insufficient data	Small deterioration
8. Grays Harbor	Insufficient data	Insufficient data	Small deterioration
9. Willapa Bay	Insufficient data	Insufficient data	Small deterioration
10. Columbia River	Insufficient data	Insufficient data	No change
11. Nehalem River, Tillamook Bay, and Netarts Bay are unknown for future outlook and overall eutrophic condition.			
14. Siletz Bay	Insufficient data	Insufficient data	Small deterioration
15. Yaquina Bay	Insufficient data	No change	Small deterioration
16. Alsea River	Insufficient data	Insufficient data	Small deterioration
17. Siuslaw River	Insufficient data	Insufficient data	Small deterioration
18. Umpqua River	Insufficient data	Insufficient data	Small deterioration
19. Coos Bay	Insufficient data	Insufficient data	Small deterioration
20. Coquille River	Insufficient data	Insufficient data	Small deterioration
21. Rogue River	Insufficient data	Insufficient data	Small deterioration
22. Klamath River	Insufficient data	Insufficient data	No change
23. Humboldt Bay	Insufficient data	Insufficient data	No change
24. Eel River	Insufficient data	Insufficient data	Small deterioration
25. Tomales Bay	Insufficient data	Insufficient data	Large deterioration
26. Drakes Estero	Insufficient data	Insufficient data	Large deterioration
27. San Francisco Bay North	Small deterioration	No change	No change
28. San Francisco Bay South	Insufficient data	Improved	Small deterioration
29. Elkhorn Slough	Small deterioration	Improved	No change
30. Monterey Bay	Insufficient data	Insufficient data	Small deterioration
31. Morro Bay	Small improvement	Improved	No change
32. Santa Monica Bay	Small improvement	Insufficient data	No change
33. Anaheim Bay	Insufficient data	Insufficient data	Small deterioration
34. Alamitos Bay	Insufficient data	Insufficient data	Insufficient data
35. San Pedro Bay	Insufficient data	Insufficient data	Small deterioration
36. Newport Bay	Small improvement	Improved	Large deterioration
37. Mission Bay	Insufficient data	Insufficient data	Small deterioration
38. San Diego Bay	Insufficient data	Insufficient data	Large deterioration
39. Tijuana Estuary	Small deterioration	Improved	Large deterioration

Impaired uses

- Six systems had impacts to living resources.
- Human uses were reported to be impaired in only one system, for commercial and recreational fishing; other systems are unknown.

Considerable impacts to living resources were reported for Newport Bay, moderate impacts for Elkhorn Slough and Hood Canal, and slight for Klamath River, Tijuana Estuary, and Morro Bay. The reasons for impacts to living resources, noted only for Klamath River, were agriculture, upstream land use, and upriver hydroelectric and diversion projects that reduce flow downstream.

Potential management concerns

Potential sources to target for improvements to overall eutrophic condition in Washington estuaries are wastewater treatment, urban runoff, on-site animal operations, agriculture, and forestry. In southern California, wastewater treatment, urbanization, stormwater, industry, agriculture, and forestry were cited.

Data gaps and research needs

Monitoring

The estuaries of the Pacific Coast are predominantly understudied. Therefore, there is a need for baseline monitoring of basic water quality parameters on an annual time frame in these areas. Additionally, better loading estimates should be a top priority. Forecasting models for prioritization of systems for management, integration of sampling technologies, assessment of variation among current indicators, and use of restoration effectiveness measures should be encouraged. *In situ* sampling should be coordinated with programs designed for satellite and remotely sensed observations, such as the U.S. Integrated Ocean Observing System (IOOS) to maximize data resources. Data and results should also be shared with programs like the National Water Quality Monitoring Network (NWQMN) for coordinated wide distribution.

USDA National Resources Conservation Service

Downtown Seattle, Washington. As urbanization and impervious surfaces increase, more research and monitoring, and better nutrient management will be needed.

USDA Forest Service, National Wild and Scenic Rivers System

Living resources in the Klamath River, California, are impacted by river diversions and reduced flow.

Research

Priorities for research in this region include improving the understanding of: (1) improve understanding of the mechanisms involved with nutrient loads, including the role of groundwater pulses, hydrologic alteration, impervious surfaces, and significant weather events; (2) the interactions of complicating and synergistic factors such as food web and predator alterations, climate change, and shoreline hardening; (3) the development of operational forecasting models, and (4) development of better techniques for load and flushing estimates, and (5) refinement of the susceptibility index.

Management

It is important to evaluate impacts of various nutrient sources, including population, onsite septics (exurban areas), agriculture, wastewater treatment, atmospheric loading and deposition, impervious surfaces, and urban runoff in order to implement appropriate management measures. Integration of EPA (regulatory) and NOAA and USGS (assessment) approaches should also be explored. A much better understanding is needed of the linkages between nutrient inputs, productivity, and eutrophication.