# Coral Reefs, Bleaching & Global Climate Change: Status & Management Implications for the U.S. Remote Pacific Islands

by Jim Maragos, Coral Reef Biologist,
Remote/Pacific Islands National Wildlife Refuge Complex
U.S. Fish & Wildlife Service, Honolulu, Hawaii

**Major collaborators and contributors:** NOAA Fisheries Honolulu Laboratory, U.S. Fish and Wildlife Service, UC Santa Cruz, Oceanic Institute, Bishop Museum, University of Hawaii

# U.S. remote islands and atolls of the tropical Pacific (PRIAs)*

**U.S. Line Islands:**
Johnston Atoll NWR
Kingman Reef NWR
Palmyra Atoll NWR
Jarvis Island NWR

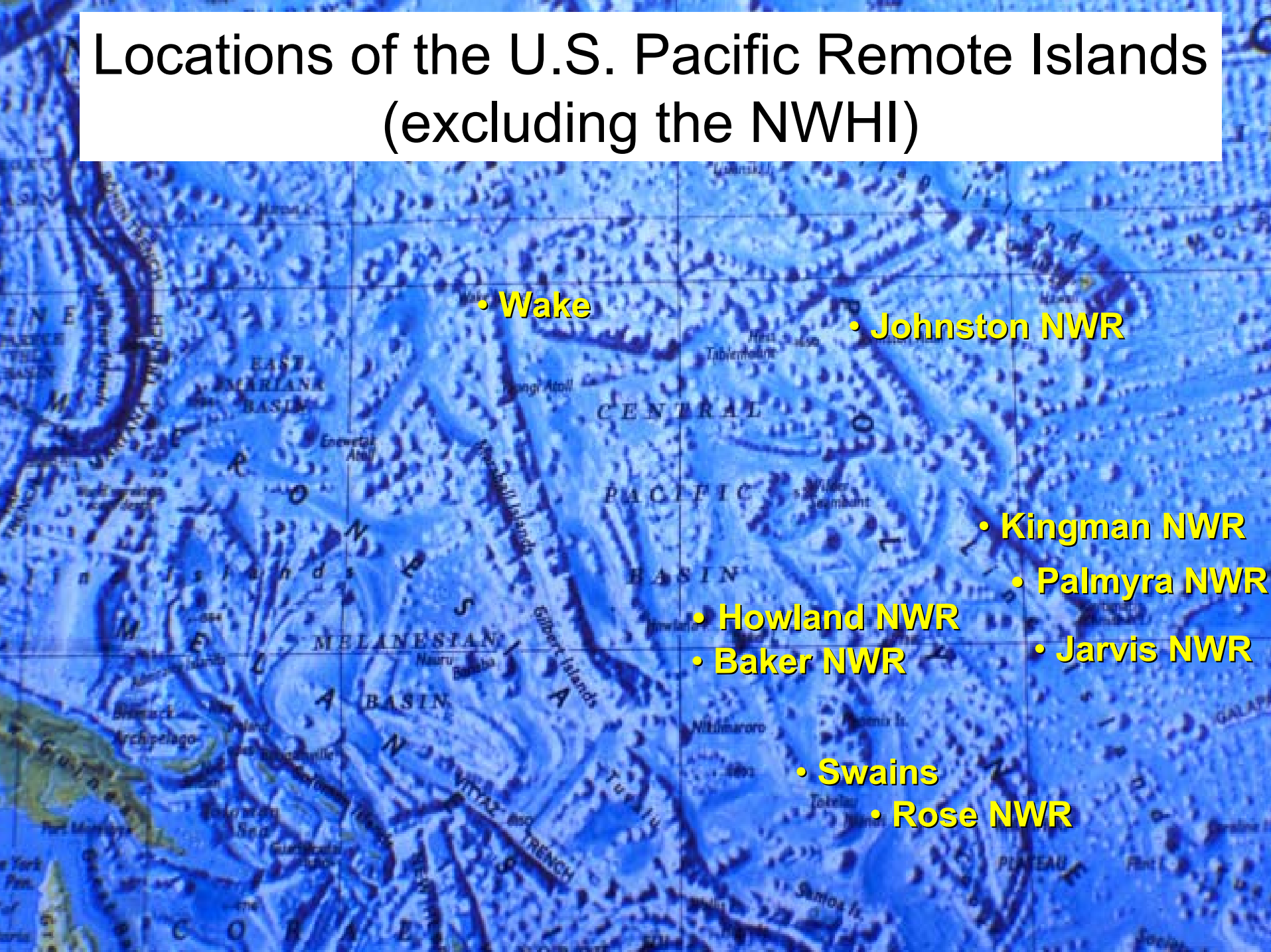
**U.S. Phoenix Islands:**
Baker Island NWR
Howland Island NWR

**Northern Marshall Islands:**
Wake Atoll

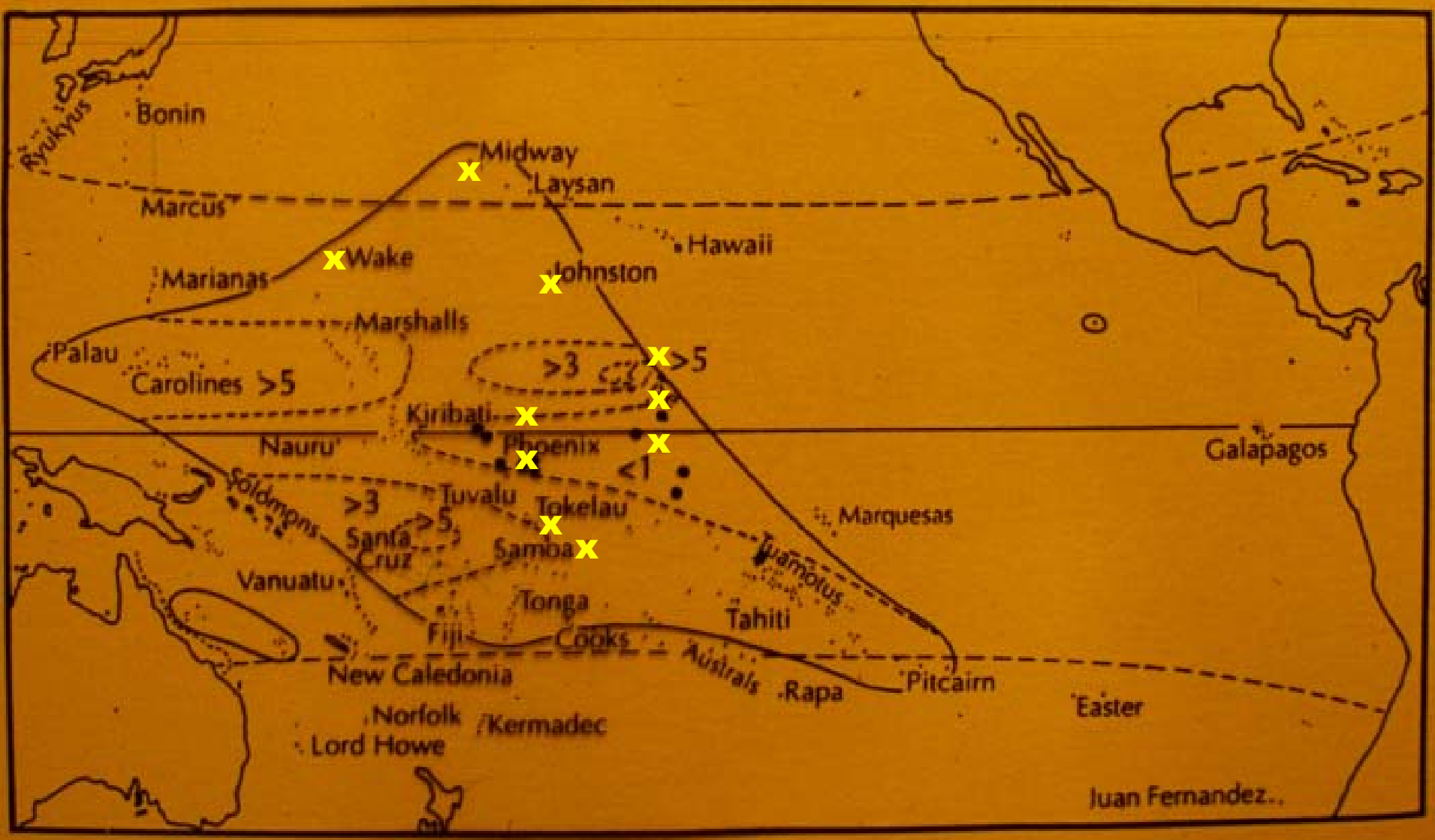
**American Samoa:**
Rose Atoll NWR
Swains Island


* Seven of the nine are National Wildlife Refuges (NWR) managed by the USFWS on a “Wildlife First” basis involving compatibility of/and permits for proposed access on & use of the refuges

# Locations of the U.S. Pacific Remote Islands (excluding the NWHI)



After David Stoddart 1992




**All of the U.S. Pacific remote islands are ancient reef islands and atolls belonging to a single geological province**

• Before 2000, most coral reefs of the US Pacific remote islands & atolls (PRIAs) had not been scientifically nor thoroughly surveyed

• NOAA Fisheries Honolulu Lab support & research vessel *Townsend Cromwell* sponsored or co-sponsored expeditions with USFWS in 2000-02, including visits to all PRIA except Wake and Johnston

• Honolulu lab is expected to continue support of expeditions to the PRIA in 2004 & beyond as part of NOAA Coral Reef Ecosystem Investigation & the USFWS Pacific Coral Assessment & Monitoring Program

• U.S. Coast Guard, U.S. Fish & Wildlife Service, NOAA & Dept. of Defense have sponsored other expeditions to the PRIAs over the past several decades

NOAA R/V *Townsend Cromwell* at Baker Island NWR, 2000

# Participating scientists on each expedition were organized as part of several teams

- benthic team (algae, corals and other invertebrates)
- coral settlement/recruitment
- oceanographic team
- towed diver team
- fish team
- land team

Jarvis Island NWR, 2000

# Fish and benthic teams accomplished rapid ecological assessments (REA) and established long-term monitoring sites

- Surveys focused on inventories of species, relative abundance, and health of reef life
- Benthic REA surveys in 2004 will include more quantitative abundance and population parameters of reef life
- Permanent monitoring sites established at all visited PRIA in 2000-02 and resurveyed during subsequent expeditions
- Long-term monitoring will be emphasized in the future & will include both permanent & roving REA sites involving improved methodology

SW Baker Island NWR, 2000

# NOAA Fisheries Honolulu Lab
# CREI: Oceanography, Coral Settlement, and Recruitment

**CREWS = Coral Reef Early Warning System**


**anchor attached to CREWS buoy at surface**

## Recruitment Plate Placement:

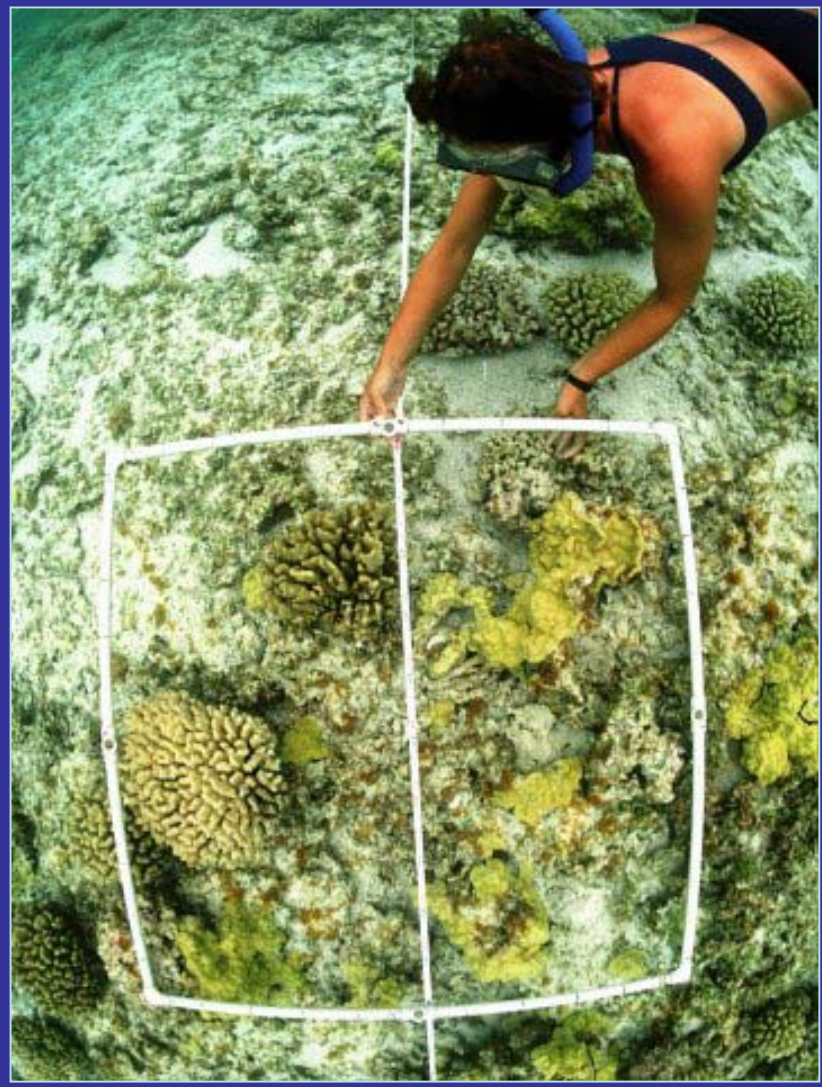
- **cardinal direction**
- **horizontal & vertical surface**
- **replication**

# NOAA Fisheries Honolulu Lab Recruitment Plates:

## U.S. Line & Phoenix Islands & American Samoa

- different plate arrangement relative to CREWS buoy plates
- deployed February/ March 2002 for 2 years
- fresh plates to be installed
- association with instrumented mooring enables knowledge of environmental parameters

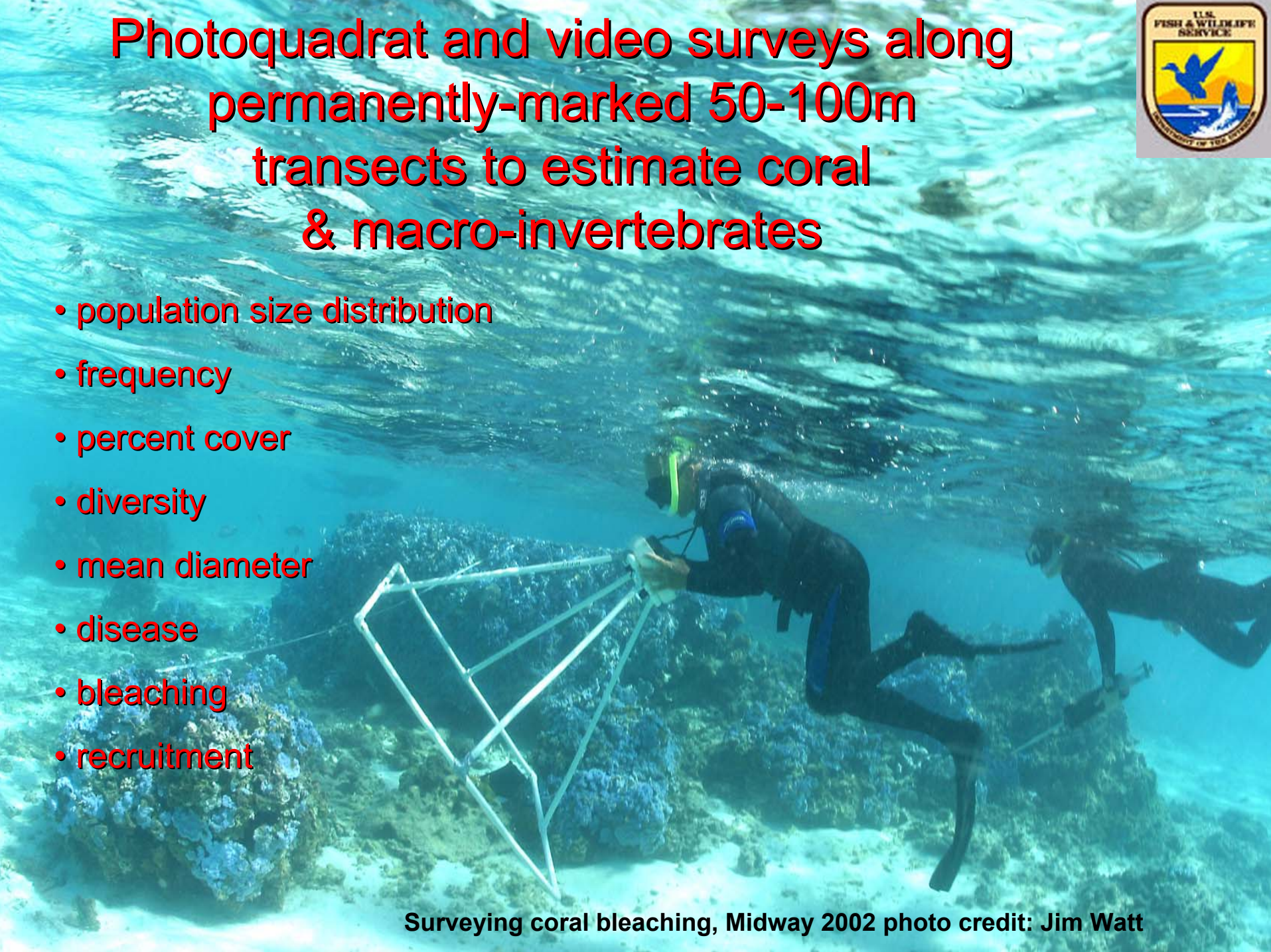
# USFWS Long-Term Monitoring: Permanently Marked Transects



- return in subsequent years and re-photograph along transect length & measure
- change in corals, inverts, algae & reef communities over time
- temperature recorders also attached at some sites

# Photoquadrat and video surveys along permanently-marked 50-100m transects to estimate coral & macro-invertebrates

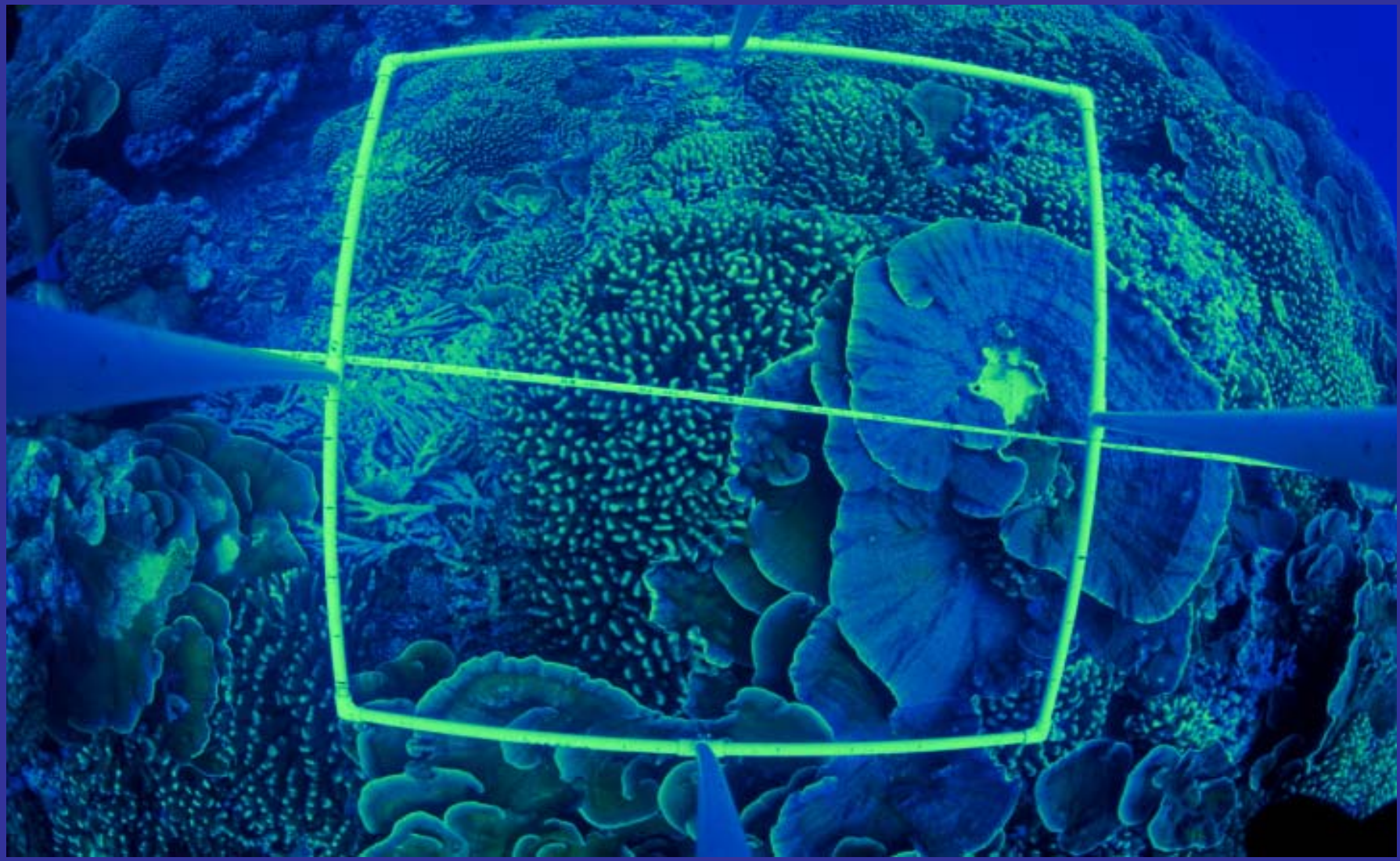
- population size distribution
- frequency
- percent cover
- diversity
- mean diameter
- disease
- bleaching
- recruitment



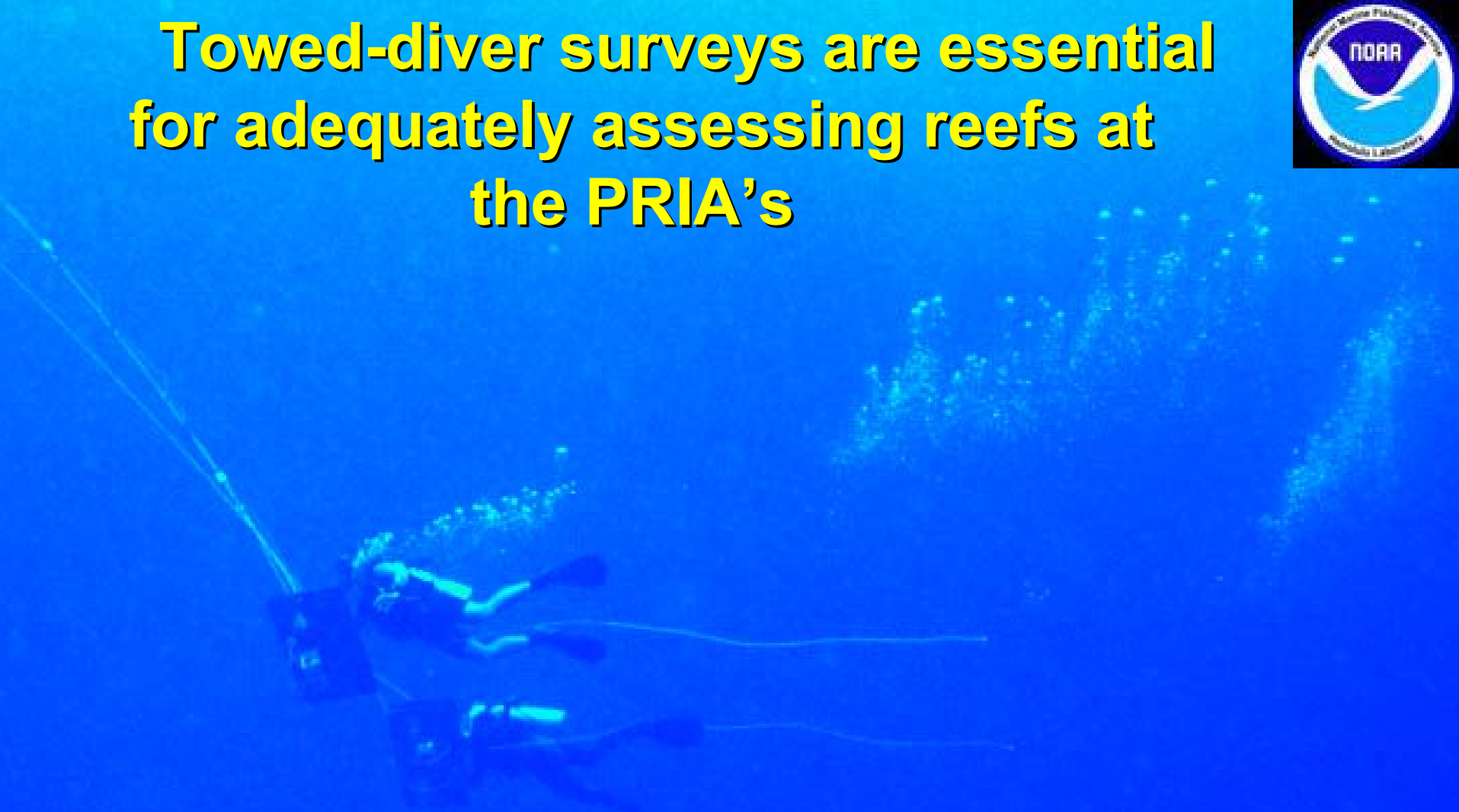
Surveying coral bleaching, Midway 2002 photo credit: Jim Watt

# Photo-quadrat along a permanent transect Swains Island, 2002:

**(Thirty-four permanent monitoring sites have been established, representing all PRIA's except Wake)**



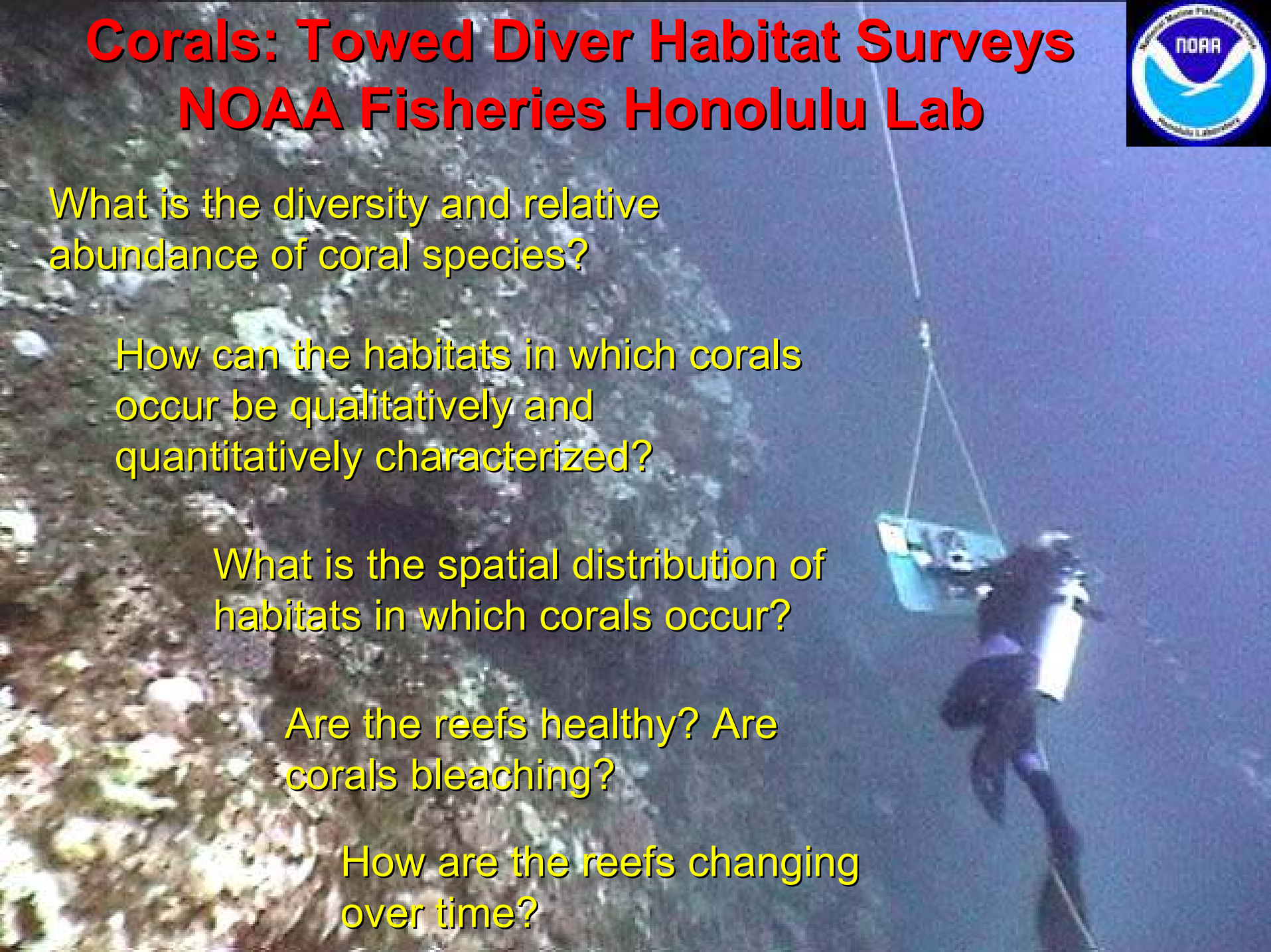
# Towed-diver surveys are essential for adequately assessing reefs at the PRIA's



- maximum of 6 to 9 dives lasting an hour each per year at each PRIA, due to high cost of ship time & extensive travel time among the PRIA's

- Each tow-board team takes notes and collects downward and forward pointing video along an average of 3 km of reef/one hour dive

# Corals: Towed Diver Habitat Surveys
# NOAA Fisheries Honolulu Lab



What is the diversity and relative abundance of coral species?

How can the habitats in which corals occur be qualitatively and quantitatively characterized?

What is the spatial distribution of habitats in which corals occur?

Are the reefs healthy? Are corals bleaching?

How are the reefs changing over time?

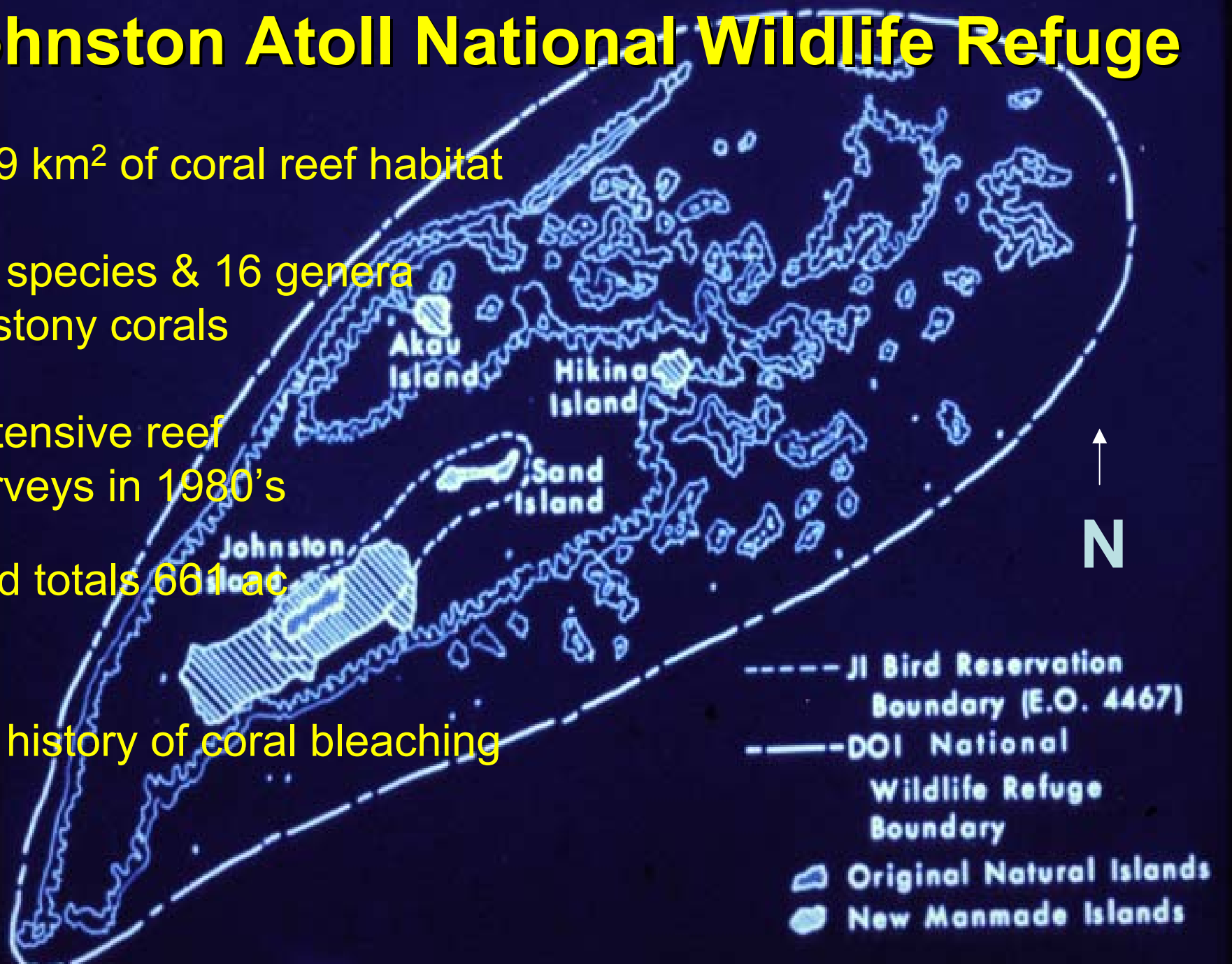
# Johnston Atoll
# National Wildlife Refuge

- 1856 - claimed by the U.S. via the Guano Act
- 1926 - afforded protection as a U.S. seabird reservation
- 1940's to 1960's - U.S. military dredging & filling
- 1950's to early 1960's - high atmospheric nuclear testing and a few low atmospheric malfunctions
- 1970's - Agent Orange herbicide stored along the runway and chemical munitions stockpiled from Okinawa
- 1976 - protection expanded to National Wildlife Refuge
- 1983 to 2000 - Johnston Atoll Chemical Agent Disposal System planned, constructed & operated
- present - USFWS and DoD negotiating base closure

Johnston Atoll to the south, 1996

# Johnston Atoll National Wildlife Refuge

- 239 km$^2$ of coral reef habitat
- 37 species & 16 genera of stony corals
- extensive reef surveys in 1980's
- land totals 661 ac
- no history of coral bleaching



# Johnston Atoll National Wildlife Refuge

- Unique giant table coral populations & recovery from massive dredge-and-fill operations of the 1960's
- Dredge spoil islands (e.g. Akau pictured) important for seabird nesting
- Concerns over contaminants & invasive species

photo credit: Ralph Schreiber

• NOAA/UH Hawaii Undersea Research Laboratory (HURL) sponsored 33 submersible dives to depths of 450 m to survey the geology & marine life at Johnston Atoll NWR in 1983

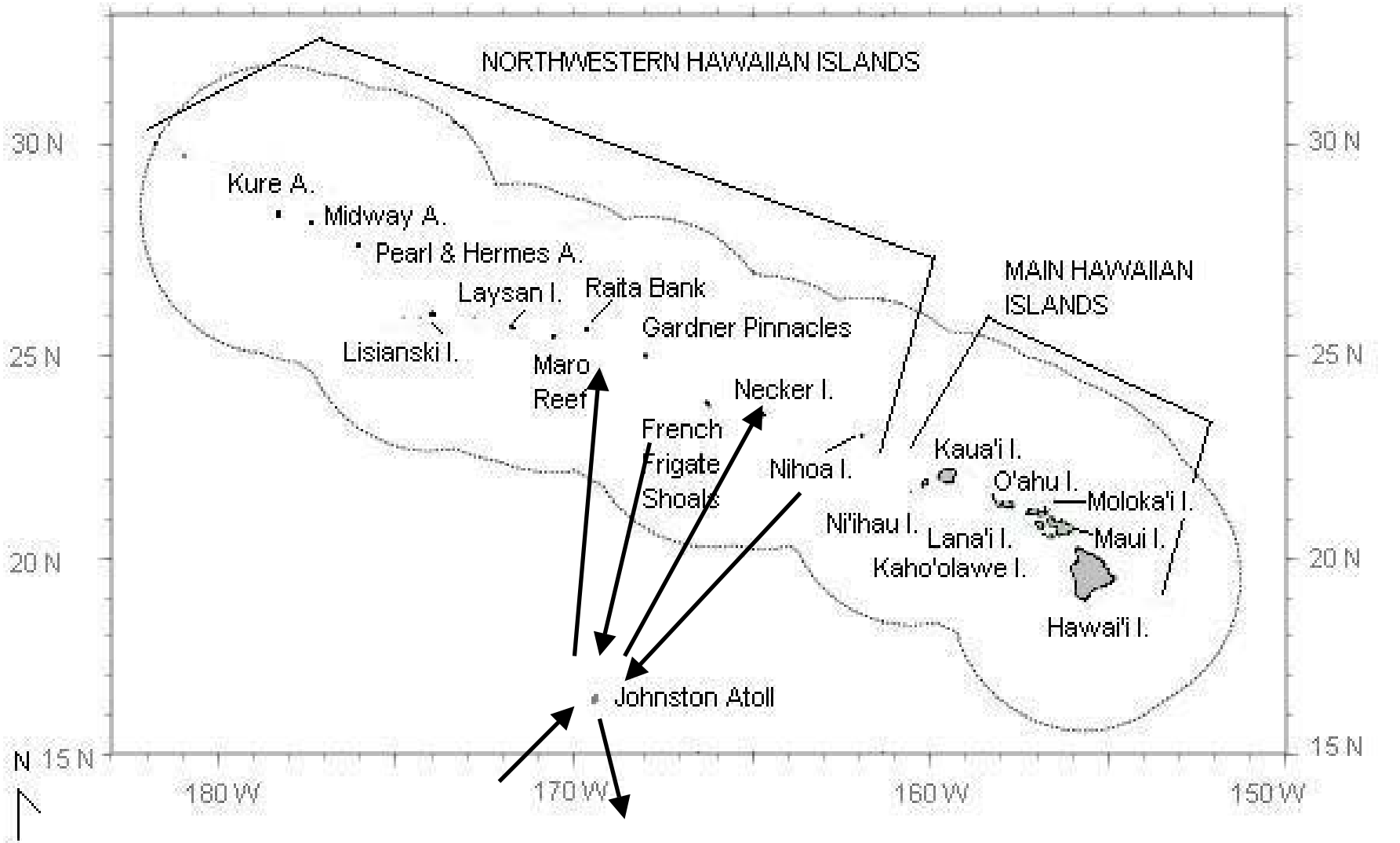
• USFWS & DoD have supported wildlife and marine research at Johnston Atoll NWR since the early 1980's


USFWS sponsored installation of 15 mooring buoys
under the direction of John Halas in 2000
8 selected as permanent reef monitoring sites

# Johnston Atoll - most northeastern Pacific outpost for hydrozoan & some scleractinian corals



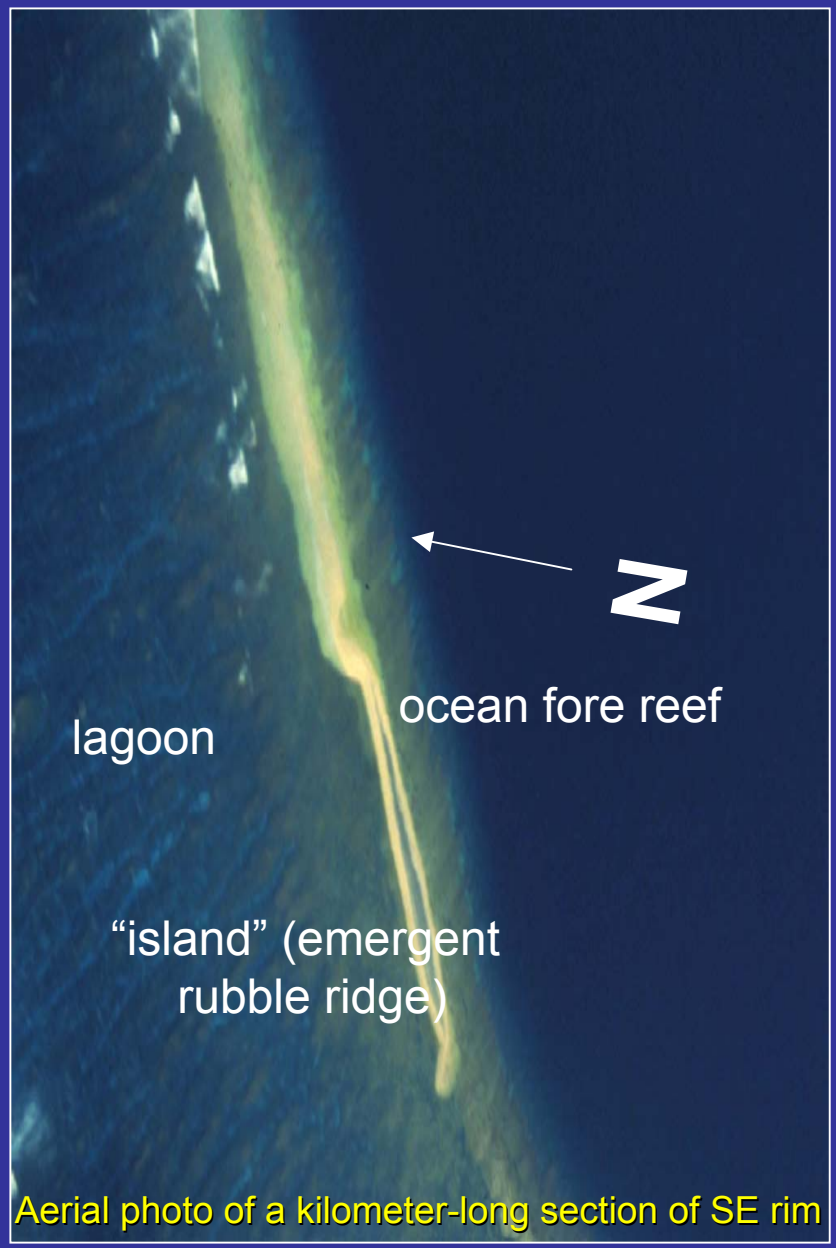

map credit: Marjo Vierros



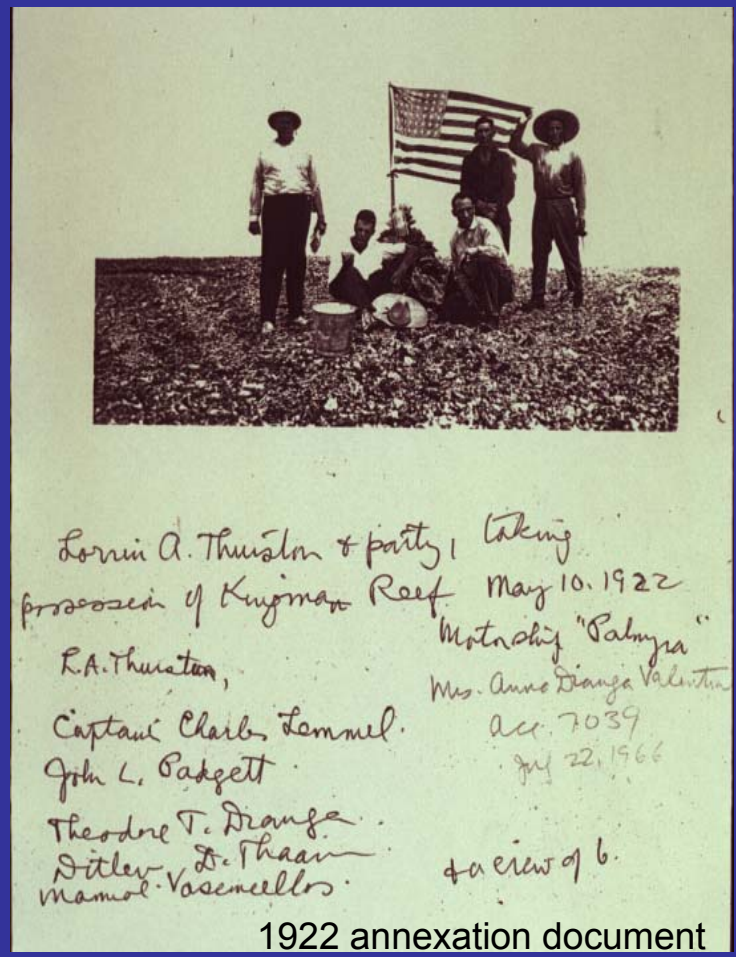

# Johnston Atoll - “stepping stone” for movement of reef species between Hawaii and the Line Islands

# Kingman Reef National Wildlife Refuge

- Claimed by the U.S. in 1922
- Used as seaplane/ship anchorage
- Declared a Naval Defensive Sea -1930's to 1940's
- Designated National Wildlife Refuge in 2001



Aerial photo of a kilometer-long section of SE rim



1922 annexation document

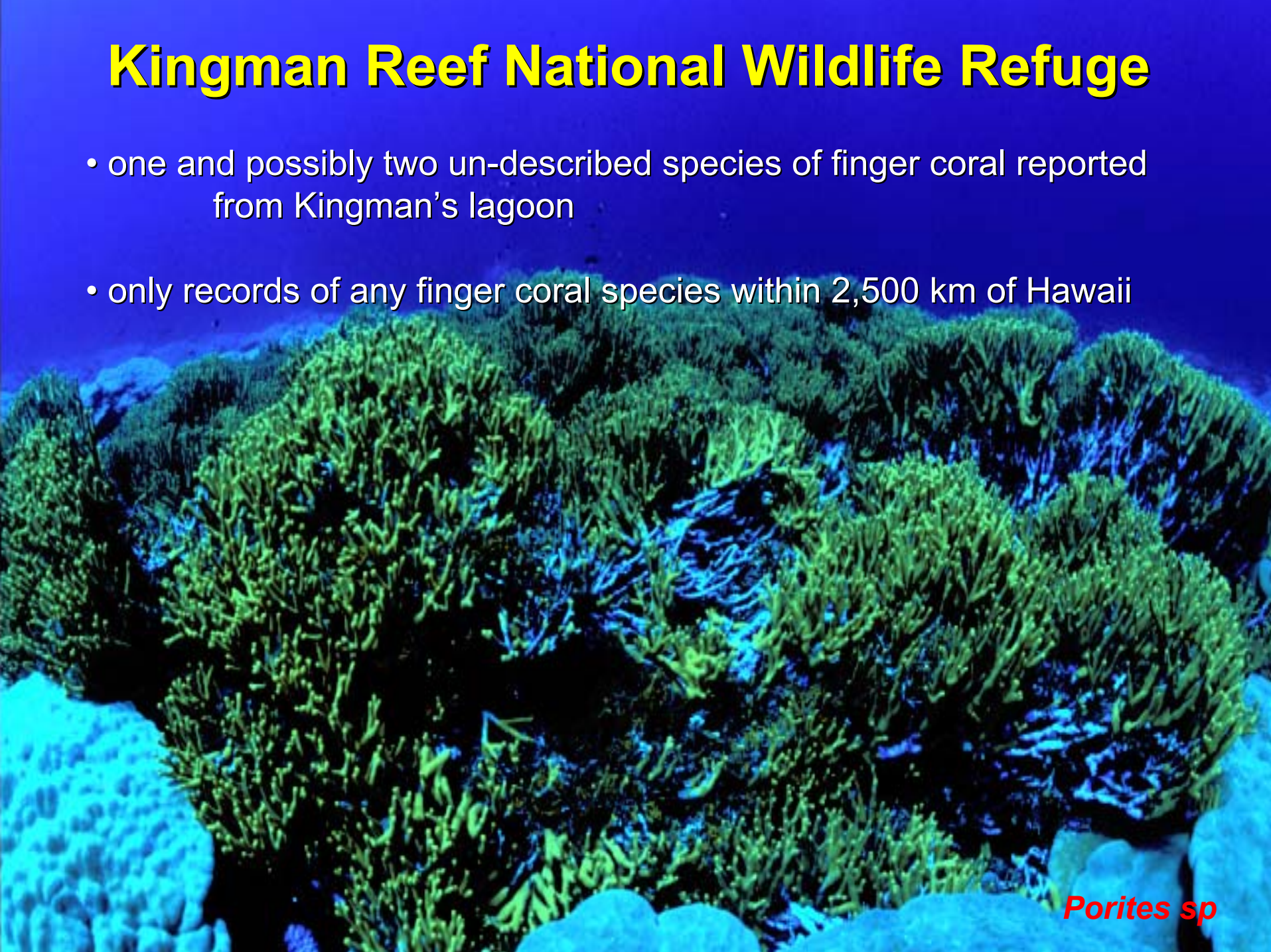
# Kingman Reef National Wildlife Refuge

- large pristine atoll reef (105 $km^2$) lacking permanent land
- among the highest coral diversity in the central Pacific:
  159 species & 46 genera reported at only 24 sites
- no evidence of coral bleaching
- eastward moving Equatorial Counter Current brings larvae from the species-rich western Pacific
- unusual abundance of mushroom corals (*Fungia),* anemones (*Heteractis),* giant clams (*Tridacna maxima)* & table corals (*Acropora*)
- unauthorized fishing is the only observable anthropogenic impact
- coral core collected & 2 permanent transects established

# Kingman Reef National Wildlife Refuge

- one and possibly two un-described species of finger coral reported from Kingman's lagoon

- only records of any finger coral species within 2,500 km of Hawaii



*Porites sp*



Kingman Reef is the northeastern limit of giant clams & some fish & cnidarians



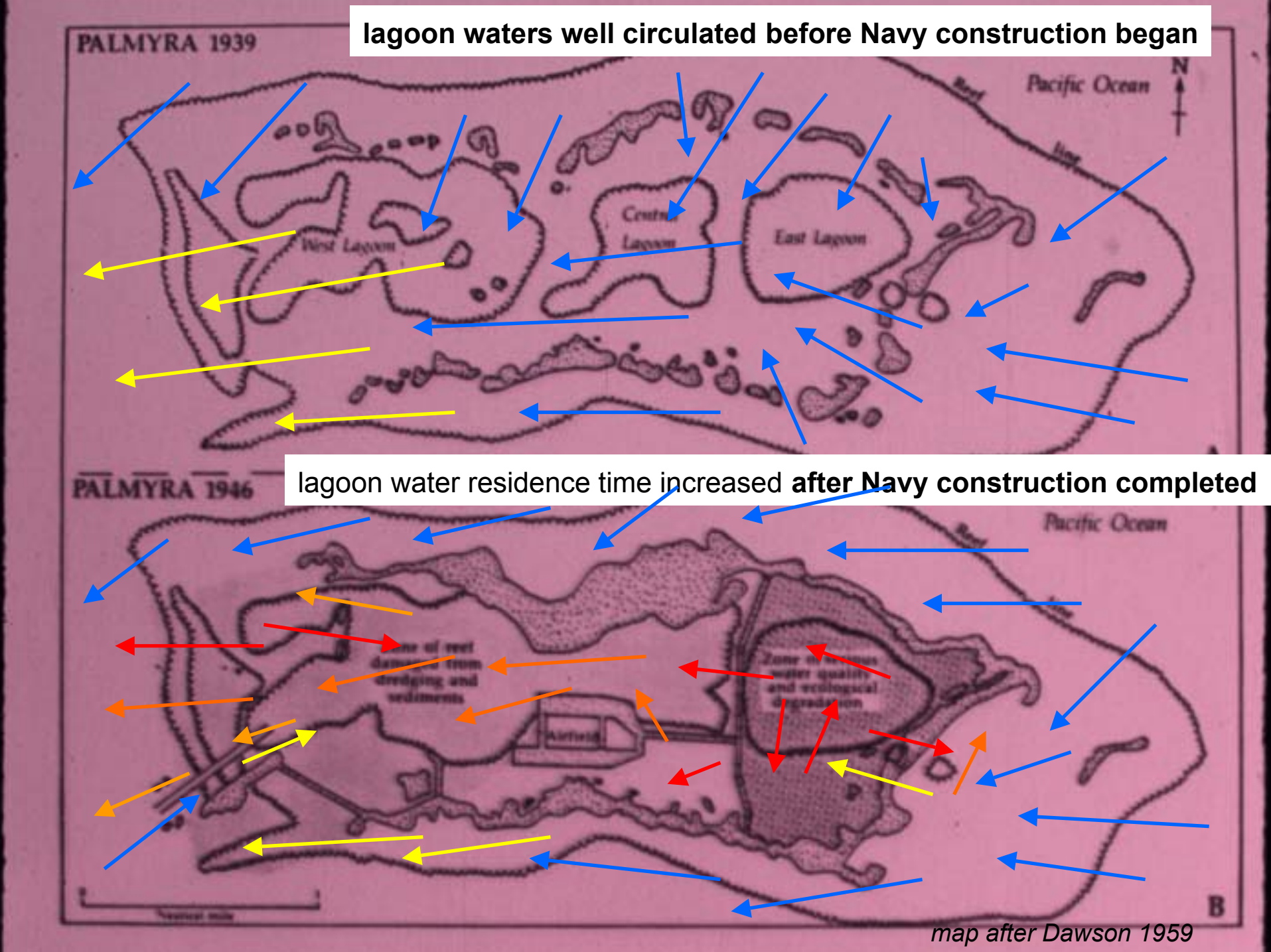


Heavy crown-of-thorns starfish (*Acanthaster)* aggregations off western reefs, noticeably controlling live coral cover at both Kingman and neighboring Palmyra Atoll NWRs

# Palmyra Atoll National Wildlife Refuge

- Palmyra (& Kingman) “discovered” in 1802
- claimed by the Kingdom of Hawaii in 1862
- U.S. annexed Palmyra following 1898 overthrow of the Hawaiian Monarchy
- acquired by Judge Cooper in early 1900’s, later purchased by Fullard-Leo family
- U.S. Navy dredged and filled reefs for military base with 6,000 troops stationed during WWII era
- deep draft channel cut through SW reef into West Lagoon
- defensive perimeter of causeways constructed, blocking lagoon circulation
- construction of main airfield on Cooper Island & smaller airfields further restricts water circulation in lagoon
- U.S. Supreme Court returned Palmyra to Fullard-Leo family in 1959
- The Nature Conservancy purchased Palmyra in 2000
- Palmyra National Wildlife Refuge established in 2001
- USFWS completes purchase of its part of the atoll in 2003

Palmyra 1987

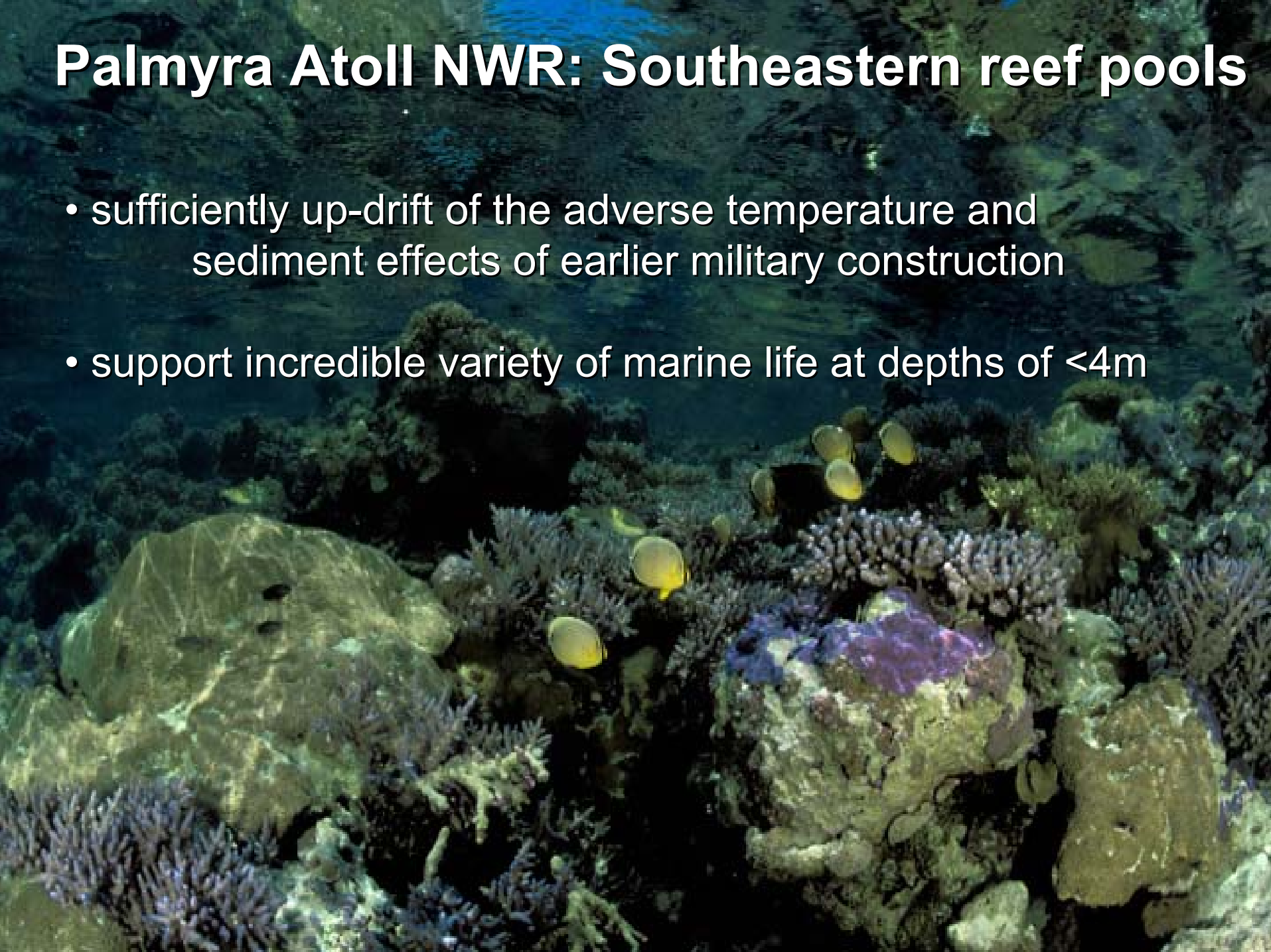



*map after Dawson 1959*

# Palmyra Atoll NWR: East Lagoon

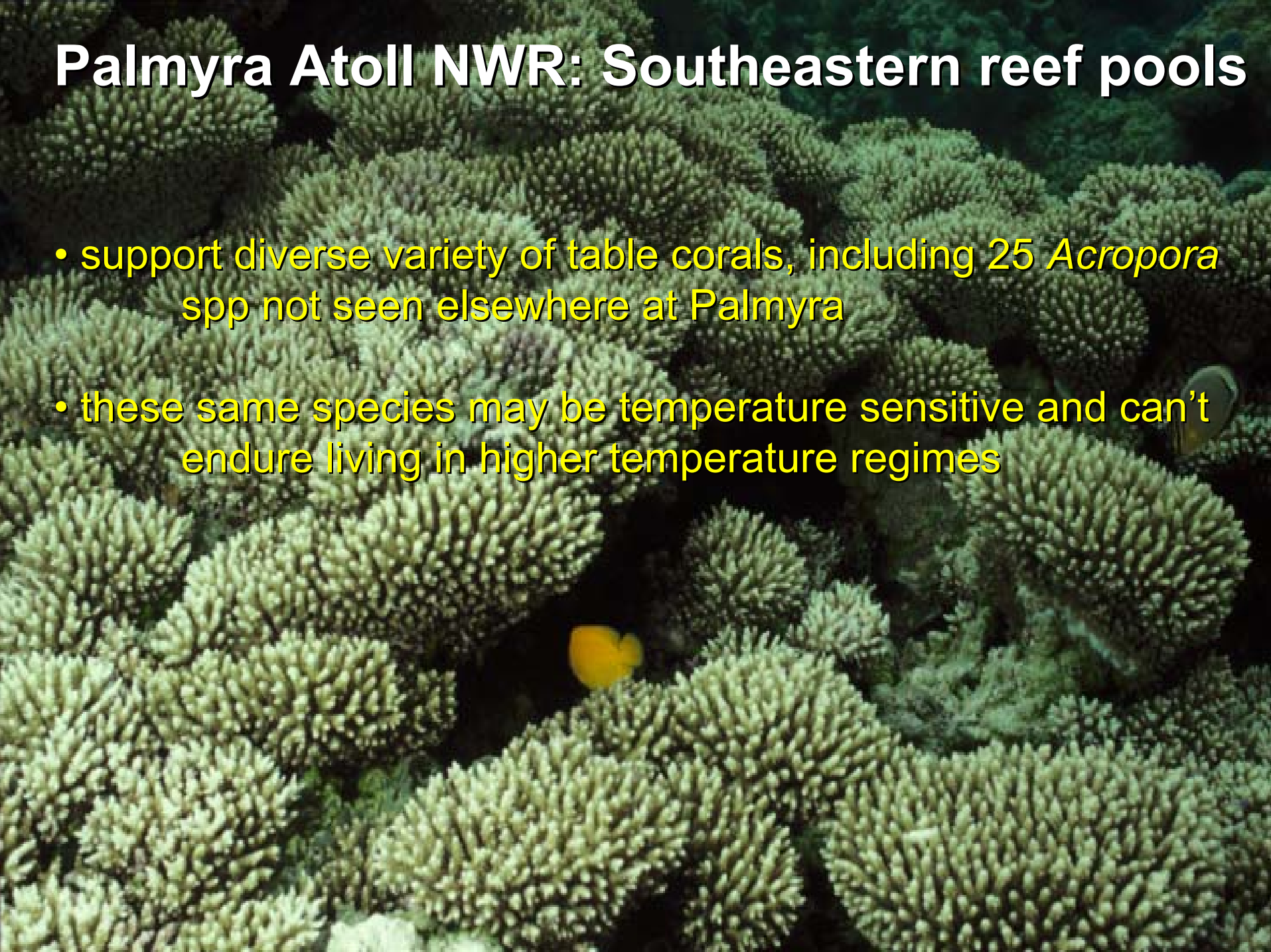
- water circulation is still very restricted
- north-south causeway prevents adequate westward movement of water
- during ebb tide, tidal flow heads back out towards the eastern reefs
- warmer turbid water from lagoon discourages inshore coral recolonization on eastern reefs
- only a few breaks through the perimeter mudflats allow mixing of lagoon and ocean waters at high tide

# Palmyra Atoll NWR: Southeastern reef pools



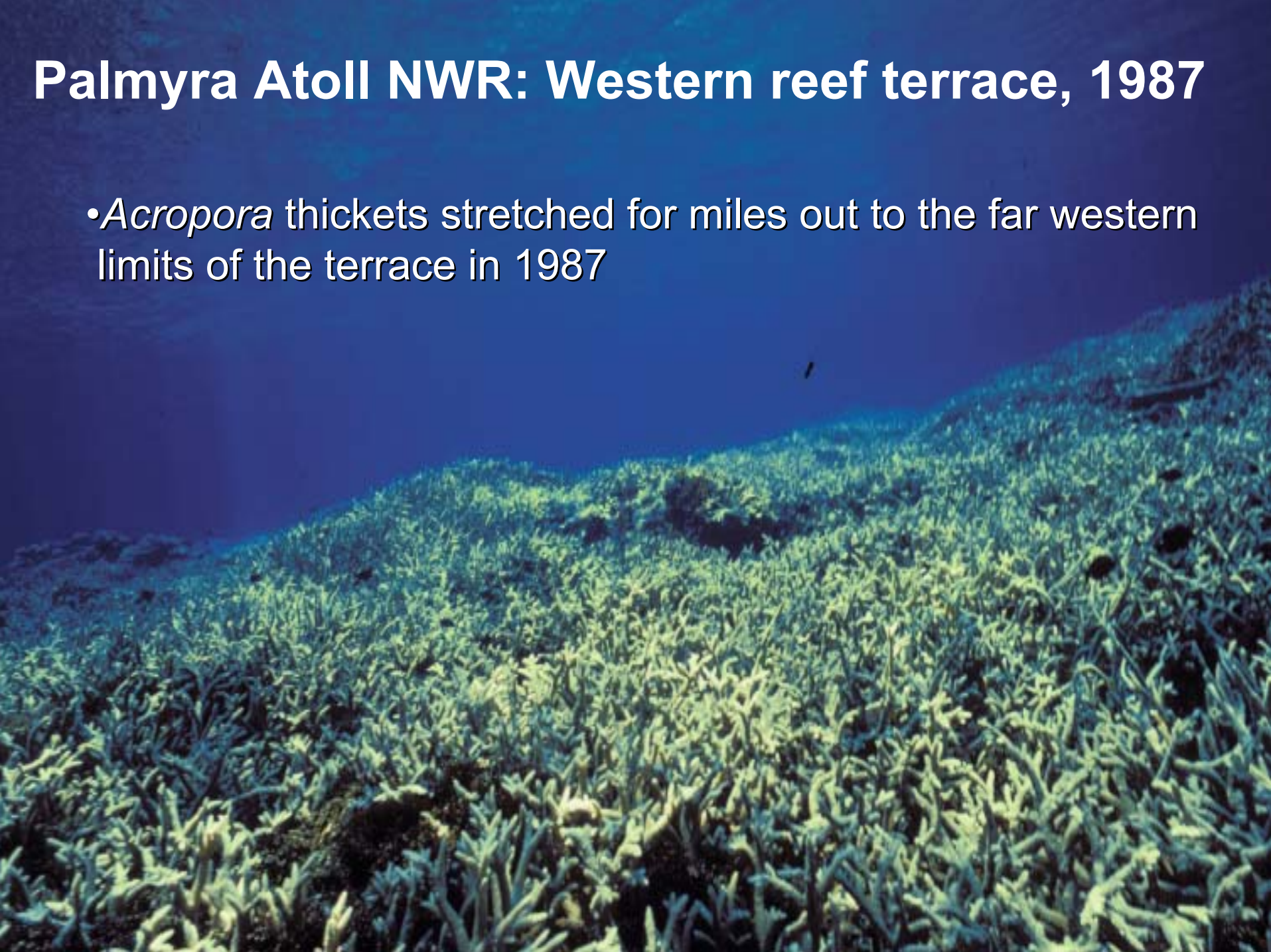
- sufficiently up-drift of the adverse temperature and sediment effects of earlier military construction
- support incredible variety of marine life at depths of <4m

# Palmyra Atoll NWR: Southeastern reef pools



- support diverse variety of table corals, including 25 *Acropora* spp not seen elsewhere at Palmyra
- these same species may be temperature sensitive and can't endure living in higher temperature regimes

# Palmyra Atoll NWR: Western reef terrace, 1987



- *Acropora* thickets stretched for miles out to the far western limits of the terrace in 1987

# Palmyra Atoll NWR: western reef terrace, 1998

- the terrace had completely changed by 1998- all the live staghorn & table *Acropora* were gone!

- interestingly, corals along the north face of the terrace were not affected & are bathed in cooler oceanic water

- in their place the dead corals were serving as substrate for young *Pocillopora & Porites* colonies

- we believe the ENSO of 1997-8 may have caused bleaching that collapsed the thickets

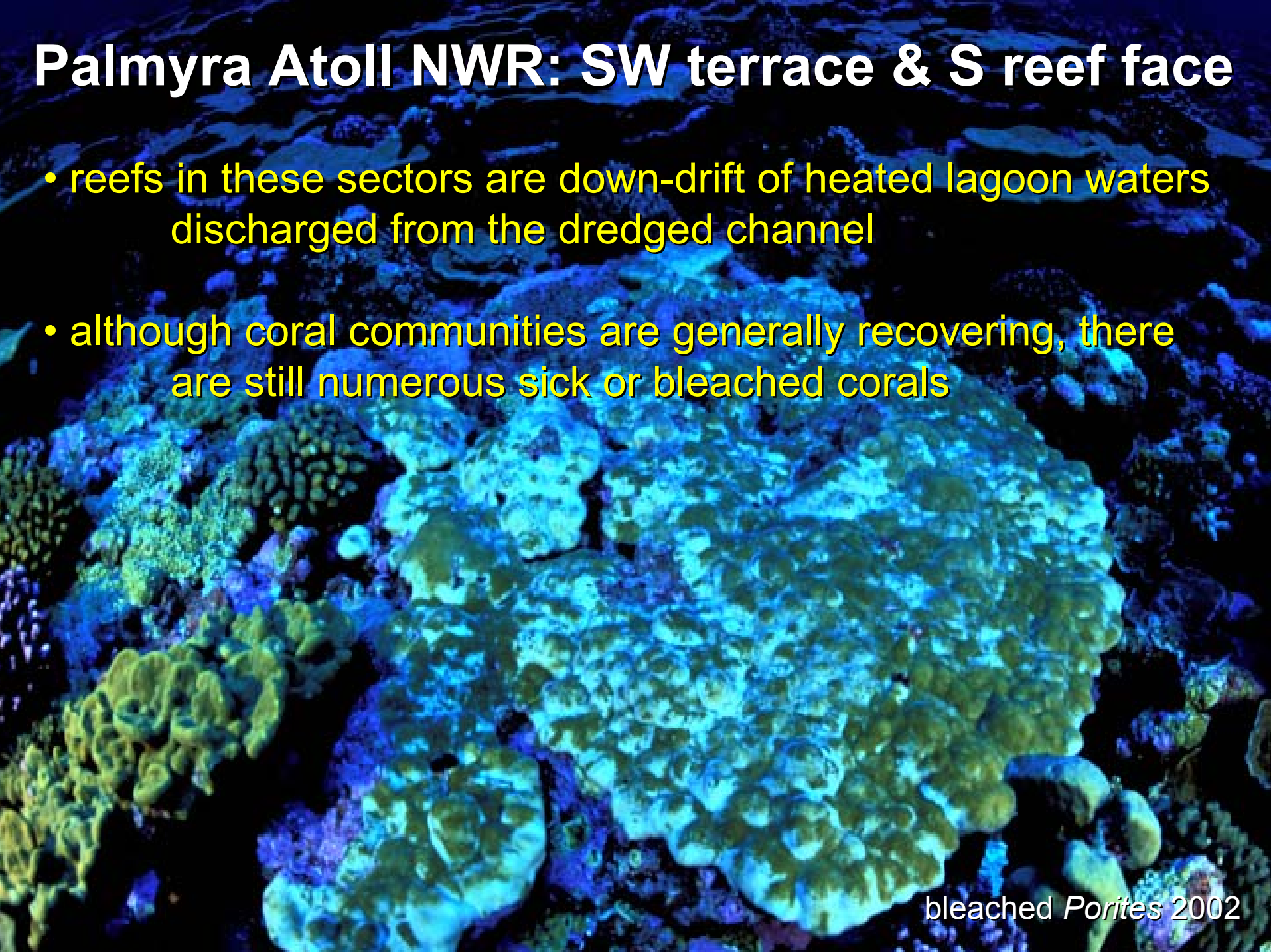
- since 2000, there has been rapid coral recovery

- the elevated ambient temperature regime caused by military construction 65 years ago contributed to the demise of corals during the 1997-8 ENSO and may contribute again during future ENSOs

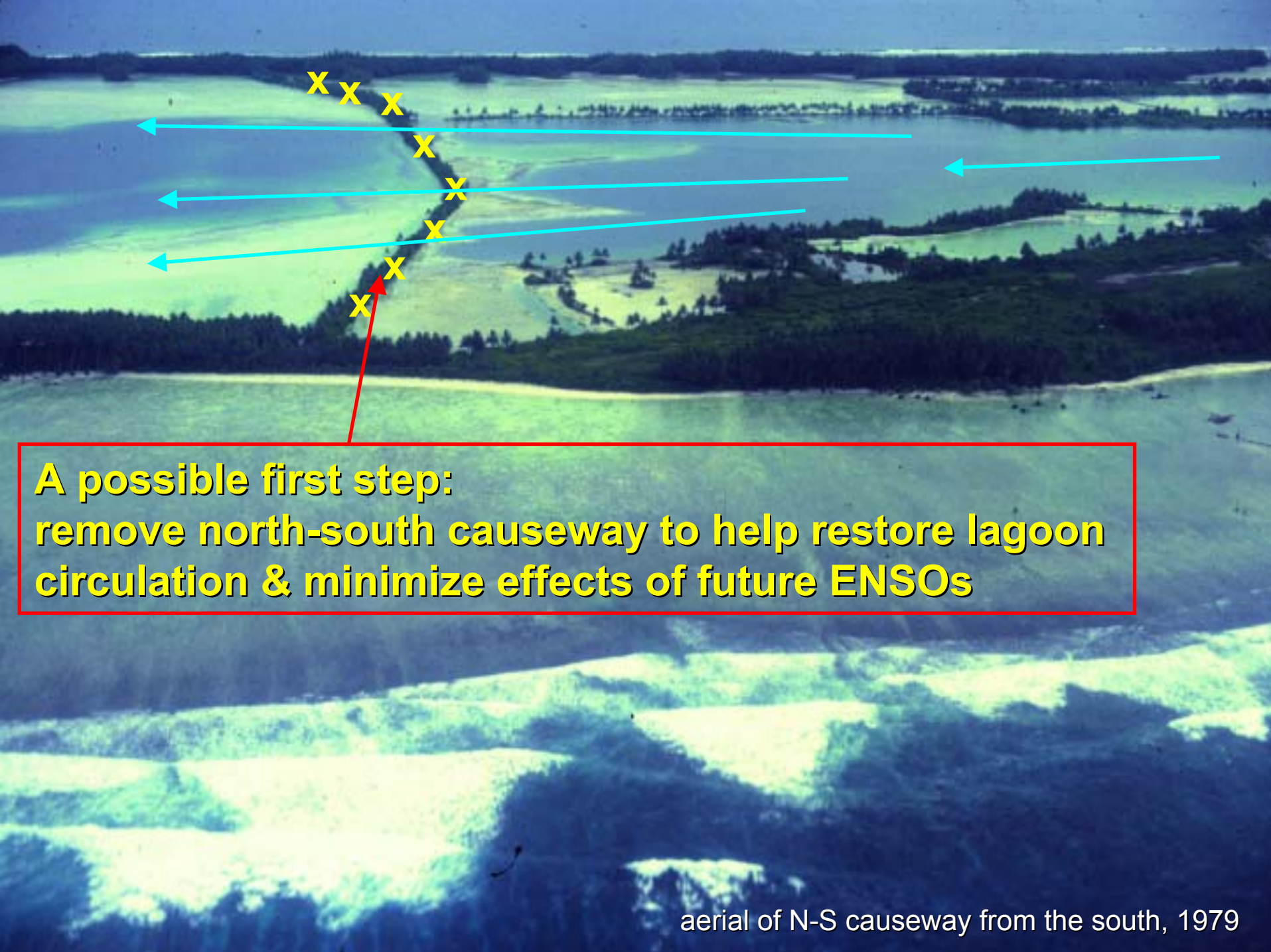
# Palmyra Atoll NWR: SW terrace & S reef face

- reefs in these sectors are down-drift of heated lagoon waters discharged from the dredged channel

- although coral communities are generally recovering, there are still numerous sick or bleached corals

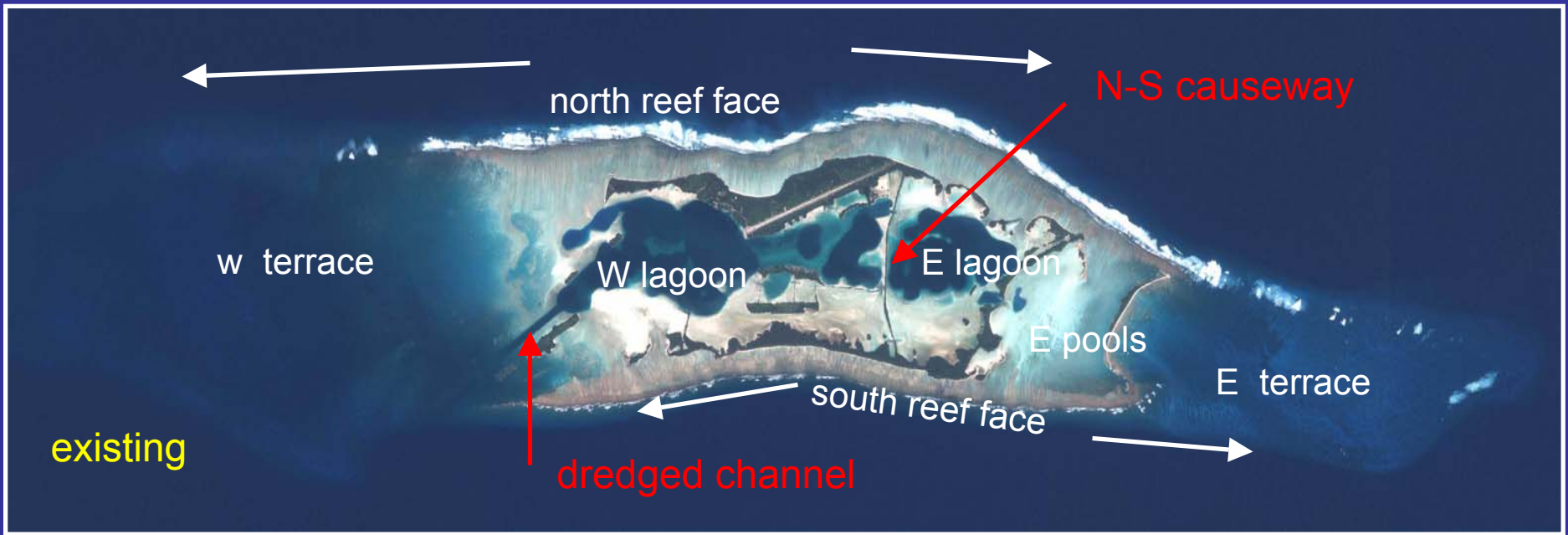


bleached *Porites* 2002




aerial of N-S causeway from the south, 1979

# Ikonos satellite images of Palmyra Atoll NWR




An important management & research priority would be to model the lagoon & determine how to fix the circulation & lower the temperature regime


Space Imaging, 2000

# Palmyra Atoll NWR: corals, reefs, and bleaching

- reefs total 65 $km^2$ & land totals 600 ac
- 169 species & 46 genera of corals at 60 sites, the most of any PRIA
- as with Kingman Reef, the Equatorial Counter Current feeds Palmyra coral larvae from the diverse western Pacific
- recent history of mass coral bleaching
- anthropogenic modifications to the atoll may exacerbate climate change effects

# Jarvis Island NWR


**total coral reef area + 8 km²**

Space Imaging, 2002

# Jarvis I., Howland I., and Baker I. NWRs: common histories and reef characteristics

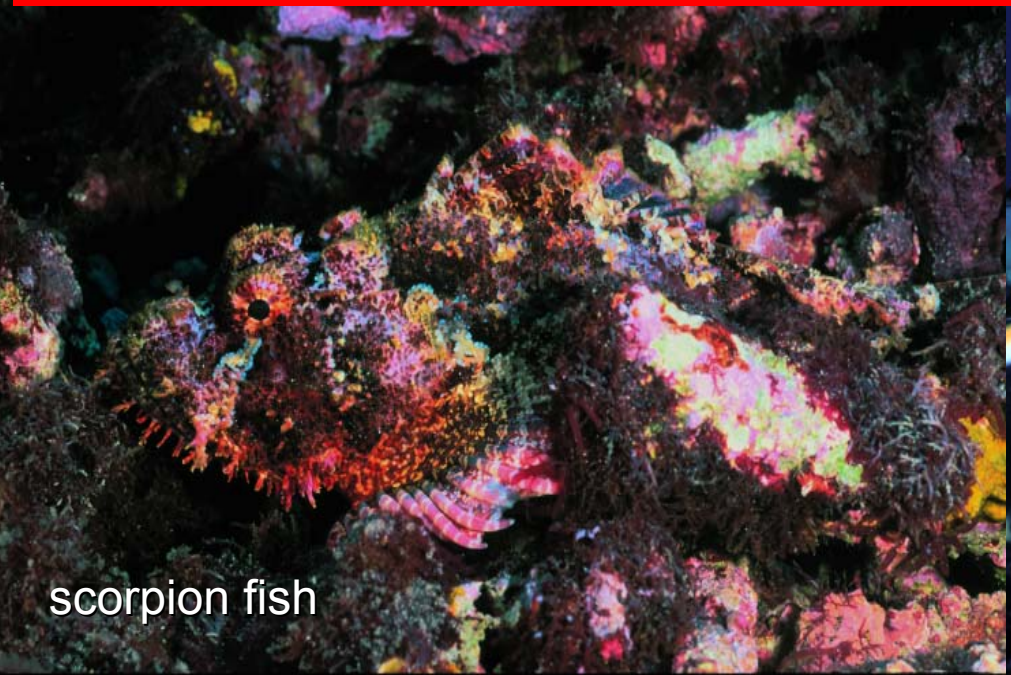
- low reef islands within one degree of the Equator in the central Pacific
- claimed by the US via the 1856 Guano Act
- occupied by Panala'au colonists 1935-42
- established as NWRs in 1972
- Equatorial Undercurrent causes upwelling
- strong evidence of recent coral bleaching

# Jarvis Island NWR


regional endemic hawkfish


Endangered Hawksbill turtle

**Jarvis supports sea turtles & abundant/diverse fish populations**


scorpion fish

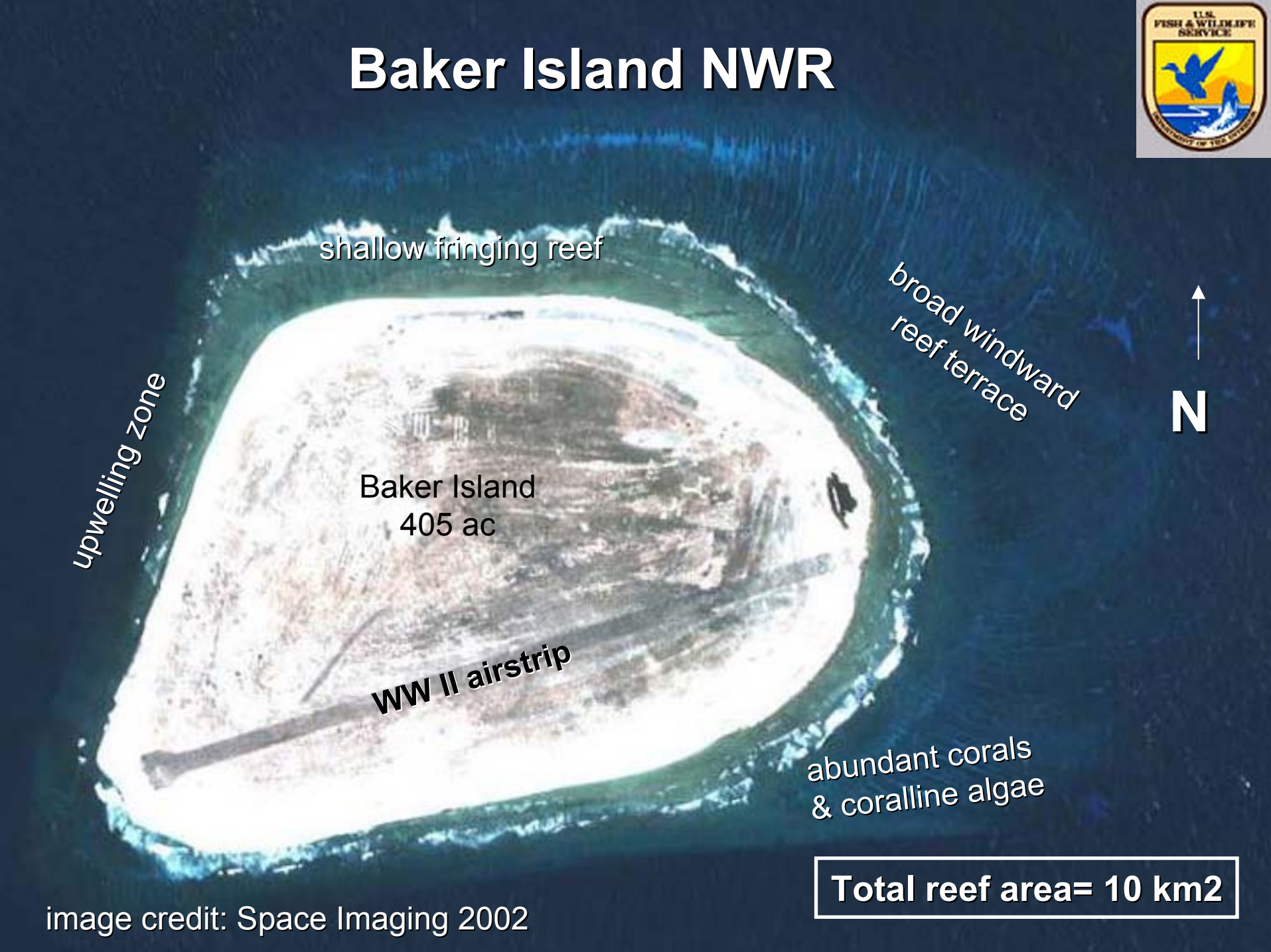

Grey reef shark

# Jarvis Island NWR: Corals

- 49 species & 21 genera of corals reported from 16 sites
- low numbers compared to other islands: geographic isolation?
- dead standing coral along steep S, N and W slopes
- broken coral deposits off the north slope
- more abundant corals on the eastern terrace
- possible new coral species (*Coscinaraea*)
- blue plate coral (*Montipora aequituberculata*) dominant & may resist bleaching *vs Acropora* which were nearly absent

*Montipora aequituberculata* & cardinal fish, Jarvis 2000

# Baker Island NWR




**Total reef area= 10 km2**

image credit: Space Imaging 2002

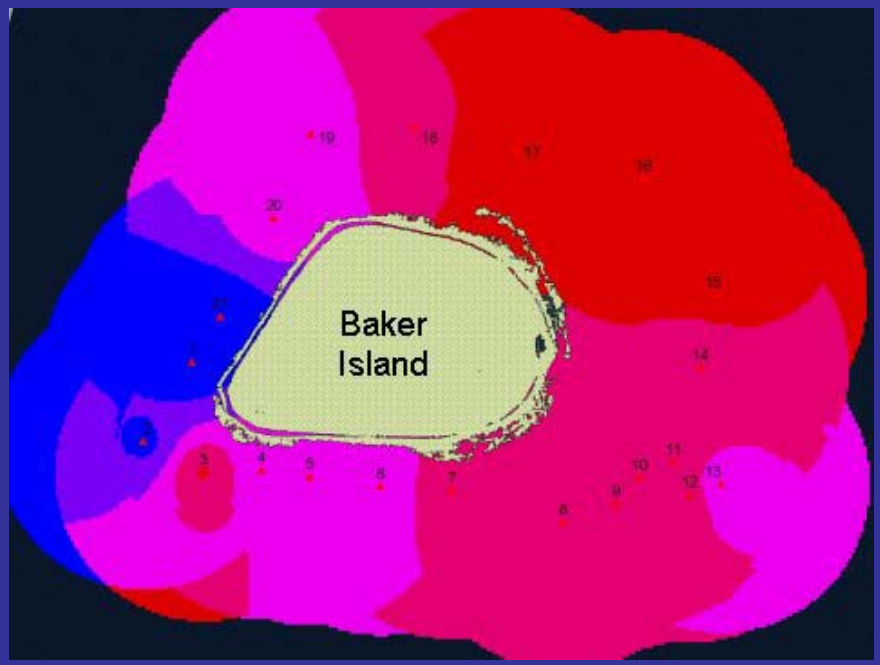
# Baker Island NWR: Corals and coralline algae

- 80 species & 30 genera of corals at 12 sites
- higher than Jarvis & comparable to those of neighboring Howland NWR
- similar patterns of abundance and distribution of corals
- dead standing corals are recent evidence of massive bleaching
- prolific coralline algae off the SE reefs with some overgrowing corals!

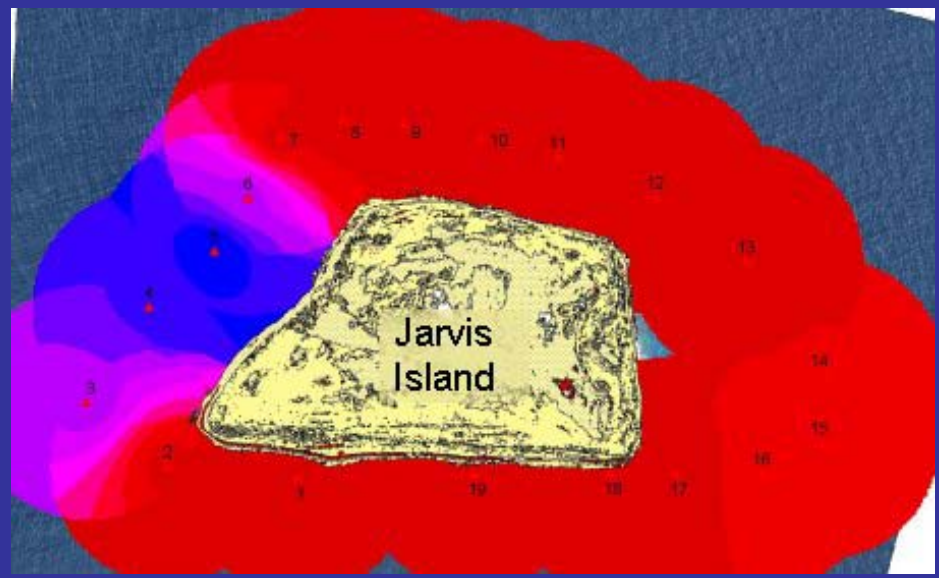
pink coralline overgrowing corals, Baker 2001


Some species of the *Acropora* table corals have not been reported outside Howland, Baker & Jarvis NWR
*Acropora* sp, Baker Island NWR

# Examples of identification of local processes



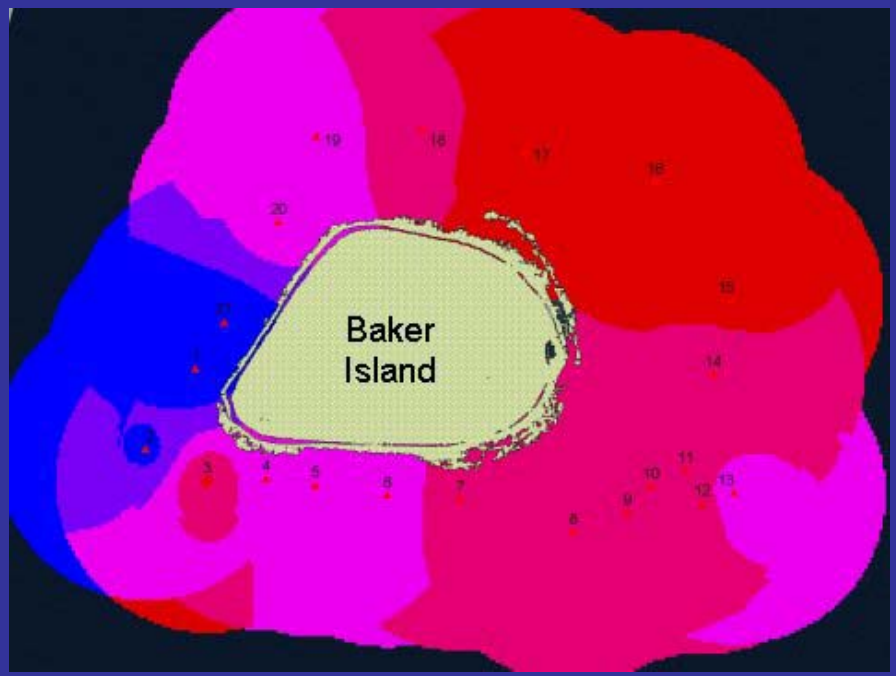


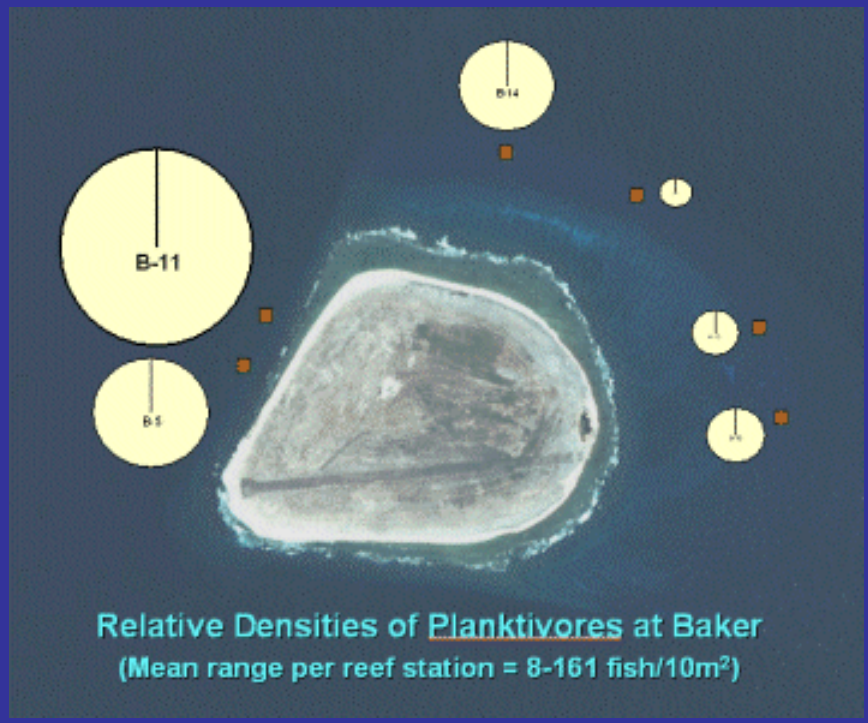



Nearest-Neighbor interpolation of CTD Station Temperatures, 2000 Equatorial Cruise

**Strong evidence of upwelling along U.S. Pacific Equatorial possessions (Jarvis, Howland & Baker)**

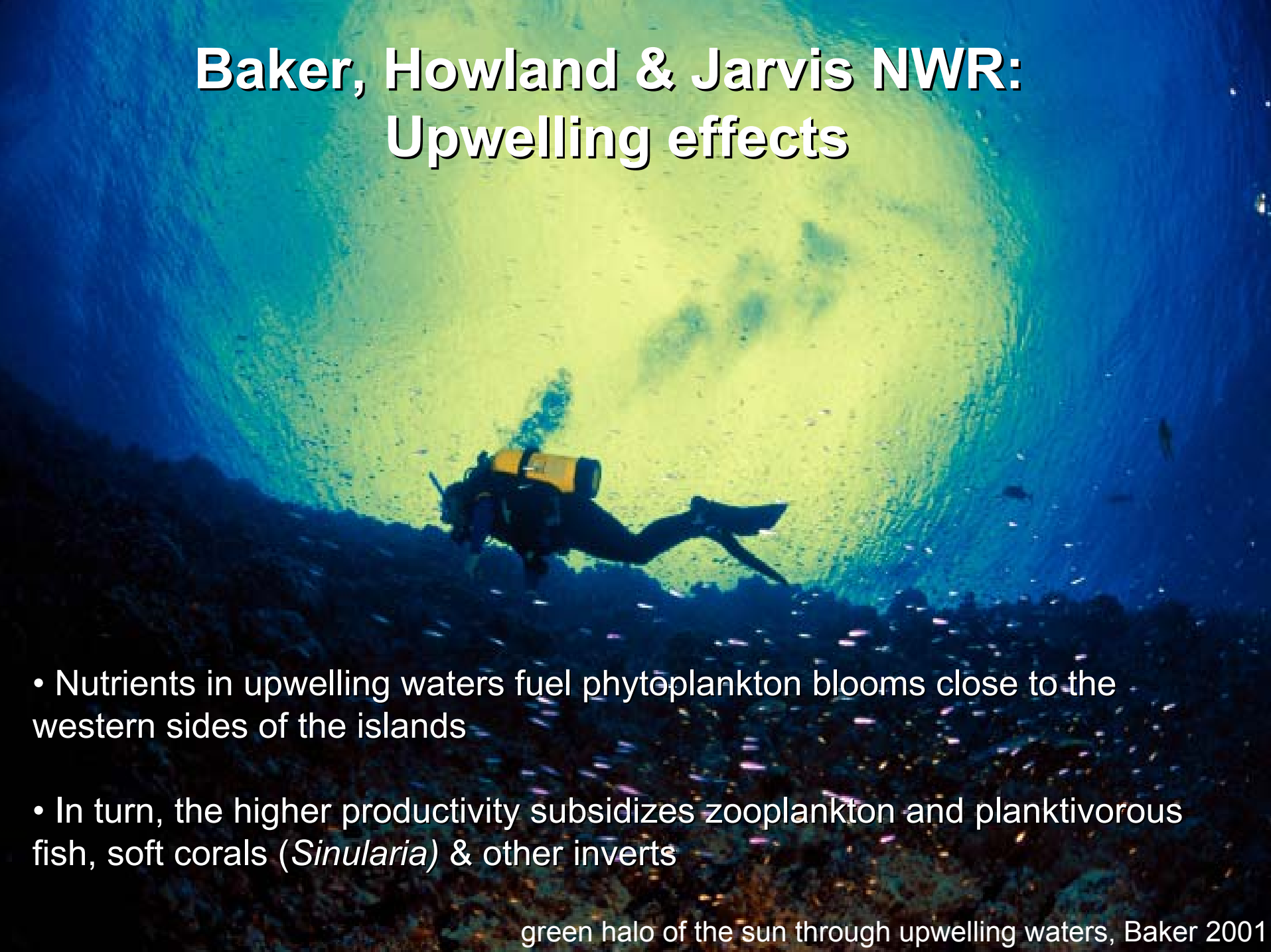
# Examples of identification of local processes




**Links between upwelling processes, including nutrient enrichment, & abundance of planktivorous fish**

# Baker, Howland & Jarvis NWR: Upwelling effects



- Nutrients in upwelling waters fuel phytoplankton blooms close to the western sides of the islands

- In turn, the higher productivity subsidizes zooplankton and planktivorous fish, soft corals (*Sinularia)* & other inverts

green halo of the sun through upwelling waters, Baker 2001


Howland Island NWR
rip currents & eddies
Total reef area= 5 km²
upwelling zone
Howland Island
455 ac
strong rip currents
shallow fringing reef
N
Space Imaging, 2002
reef terraces

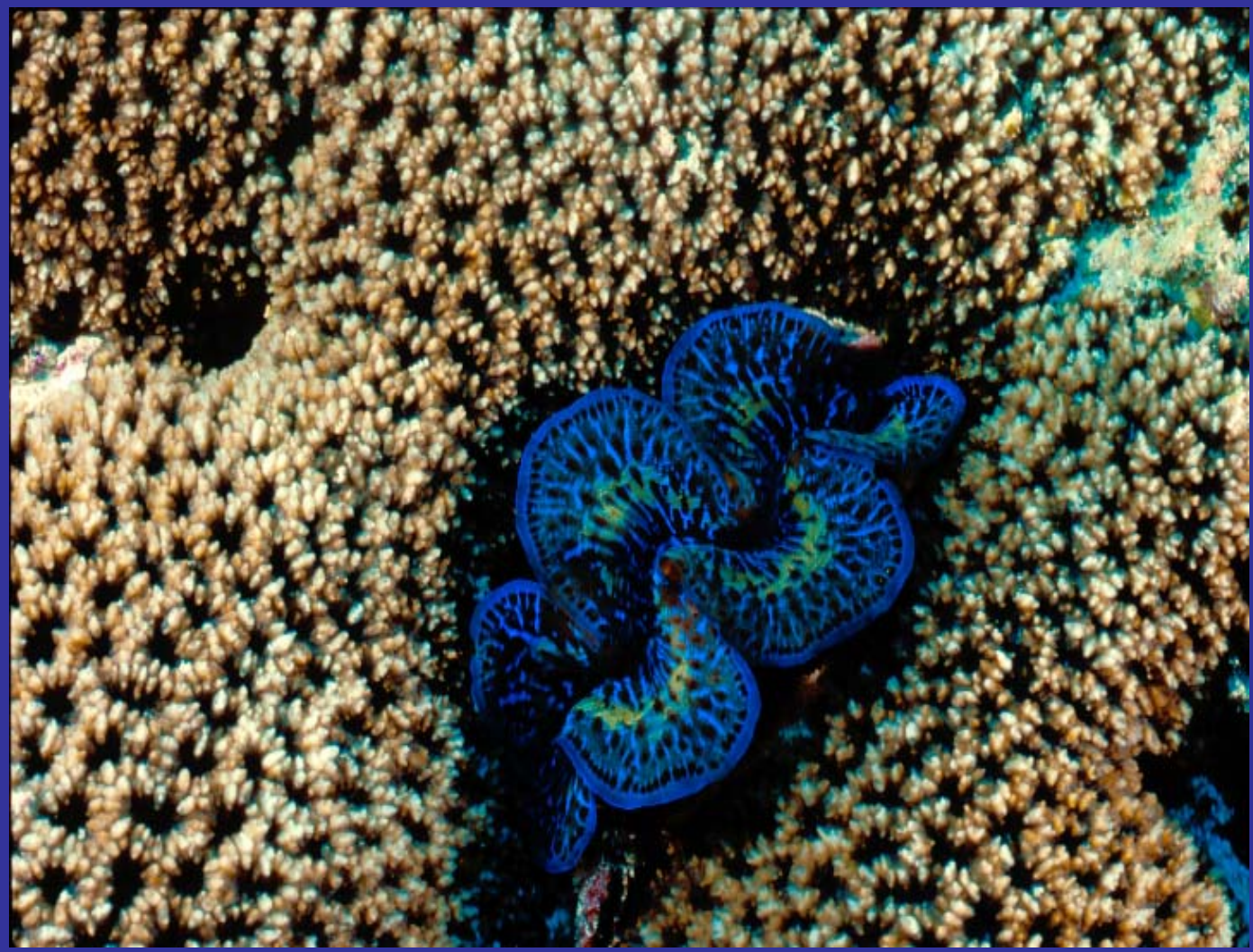
# Howland Island NWR: Corals

- 92 species and 26 genera of corals at 14 sites
- slightly more species & less genera than at Baker
- dead standing coral along western slope, indicative of recent mass coral bleaching
- table corals (*Acropora*) recovering rapidly on slopes
- strong currents and waves discouraged surveys at eastern & southern reefs

*Acropora* recolonizing western reefs at Howland, 2000

# Howland, Baker, and Jarvis NWRs

The giant clam (*Tridacna maxima),* a depleted species, was common at all three refuges



***Tridacna maxima*** **imbedded in a brain coral (*Favites*), Howland 2000**

# Rose Atoll NWR - Nu'u O Manu

- easternmost island in the Samoan Archipelago, part of the U.S. territory of American Samoa

- designated a National Wildlife Refuge in 1973


- small atoll (2 km X 2 km) with a total reef area of 7 $km^2$

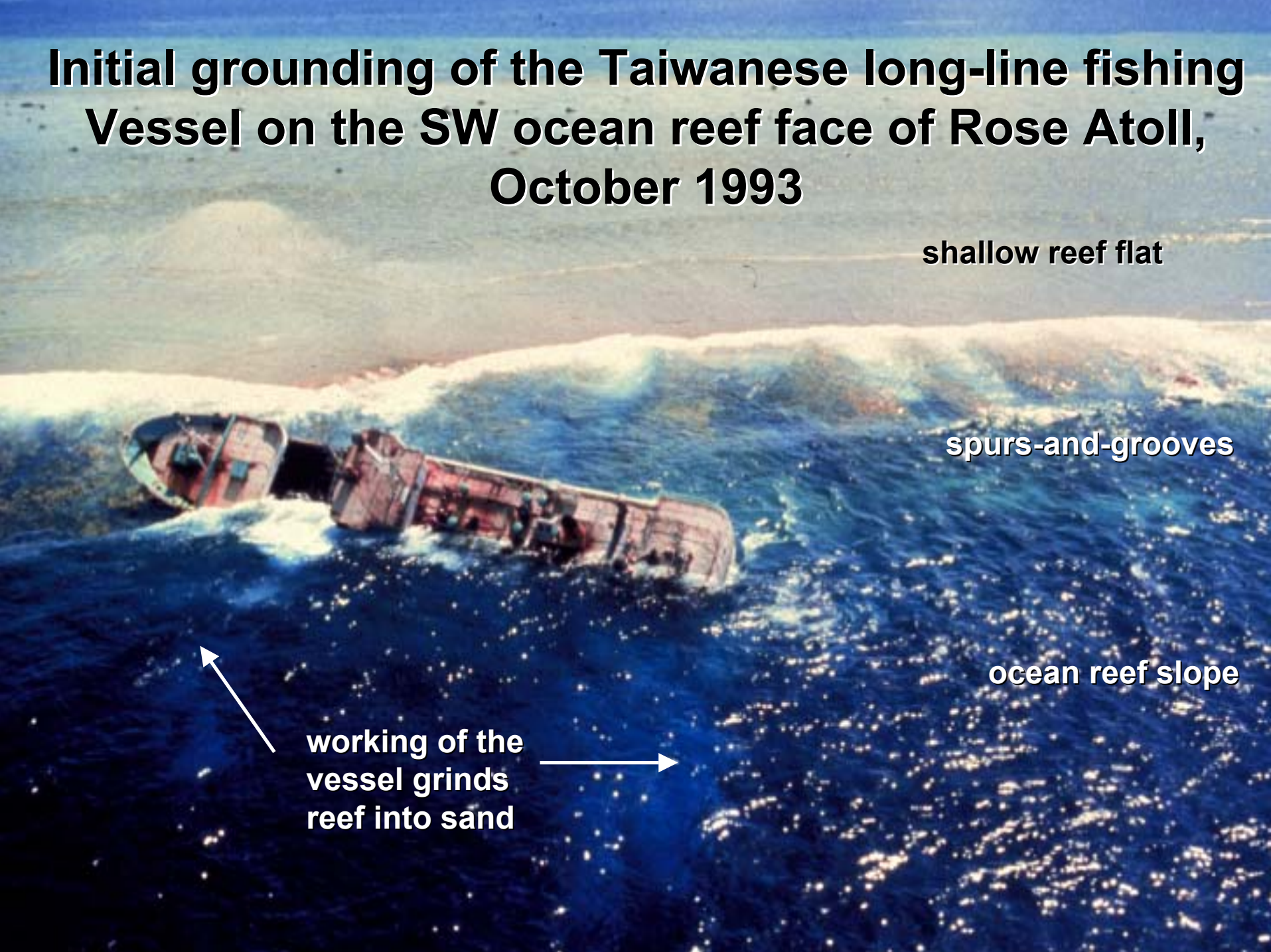
- supports the largest populations of giant clams, nesting green turtles, seabirds, and native beach forest in Samoa

aerial of Rose Atoll from west, before 1993

# Rose Atoll NWR: Corals

- 1994 & 2002 surveys yielded 94 species and 36 genera of corals at 11 sites
- following a catastrophic coral bleaching event in early 1994, five genera & over 20 species were not reported during later surveys
- coral recovery after the bleaching has been steady but slow, complicated by the grounding, fuel spill, and break-up of a Taiwanese long-line fishing vessel on the SW ocean reef in October 1993
- several years of monitoring the aftermath of the grounding was instrumental in obtaining limited USFWS funds for a cleanup
- HOWEVER, the principal reef builders (coralline algae) have not recovered

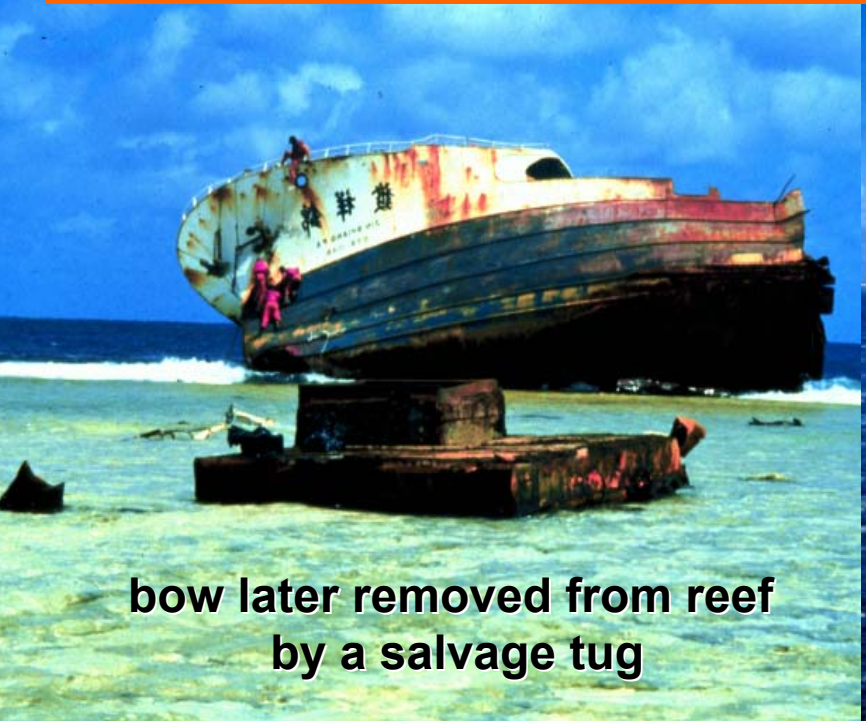
Rose Island, 2002


Initial grounding of the Taiwanese long-line fishing Vessel on the SW ocean reef face of Rose Atoll, October 1993
shallow reef flat
spurs-and-grooves
ocean reef slope
working of the vessel grinds reef into sand

Initial impact and grounding

Thousands of metallic scraps & debris cast up on the reef flat

## SW reef & fishing vessel deteriorate in a matter of weeks



bow later removed from reef by a salvage tug

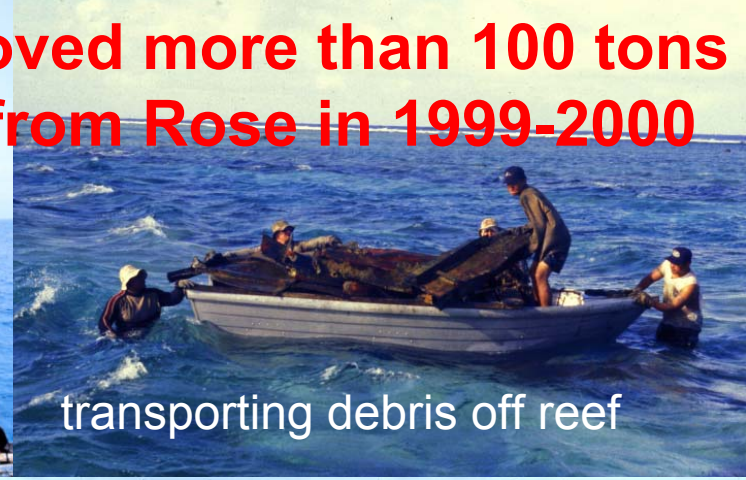
fuel spill kills off corals & coralline algae & invasive cyanobacteria cover the reef flat & slopes


Rose Is.
pass
lagoon
N
Aerial photo of Rose Atoll one year after the grounding (Oct 1994)
SW reef flat still covered with debris & cyanobacteria
shipwreck
Air Survey Hawaii

# A Samoan team removed more than 100 tons of ship metal debris from Rose in 1999-2000

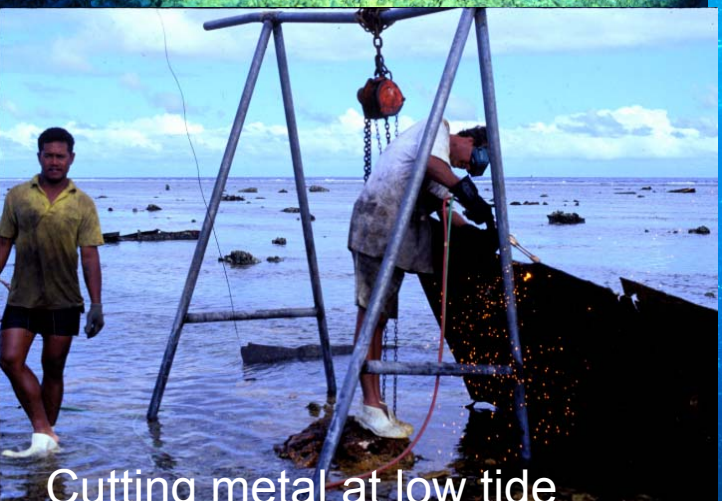

underwater cutting

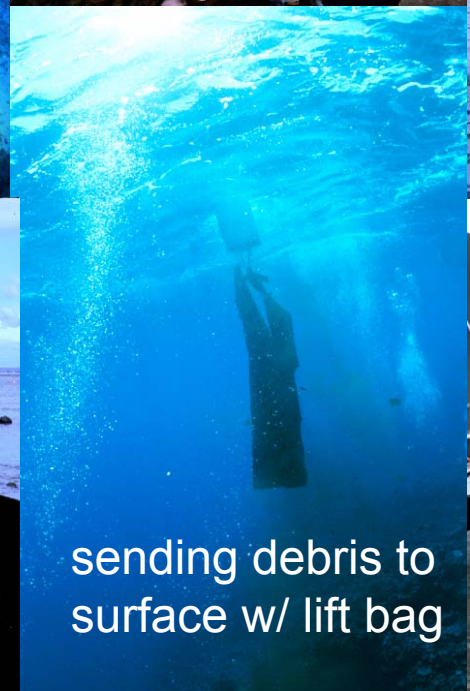

hoisting debris


transporting debris off reef


removing debris from lagoon


Rafting metal off reef at high tide


Cutting metal at low tide


sending debris to surface w/ lift bag


cleanup heroes celebrate

# Rose Atoll NWR: remaining ship debris needs to be removed

**Despite the success of the 1999-2000 cleanup, 40 tons of the heaviest metallic remains on the SW ocean reef slope. Results of recent monitoring at Rose reveal that remaining debris must be removed to facilitate removal of invasives & recovery of coralline algae**


Rose Atoll SW reef

# 2000-2 status of coral reef recovery from 1993 grounding & 1994 mass bleaching at Rose Atoll NWR

Increased fish herbivory

Invasives still dominate the flats

rose coral re-colonization

lagoon fish stocks recovering

Brain corals recolonize dead lagoon reefs

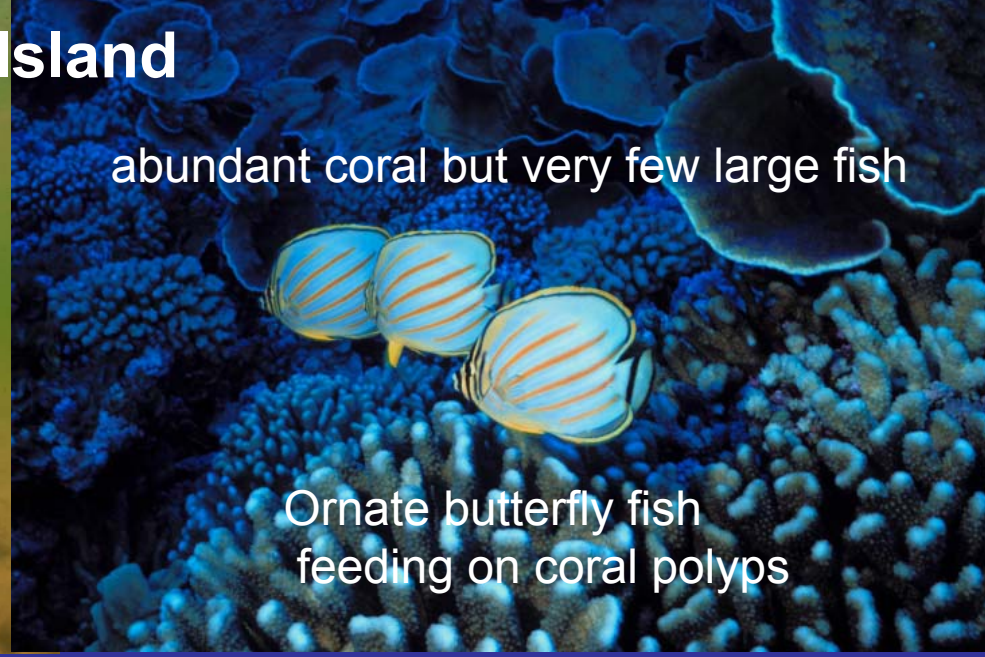

Brackish water lake in the center of the island, 2002

# Swains Island, Territory of American Samoa

- Swains is the northernmost island in the territory & geologically the southernmost of the Tokelau Islands
- in 2002, a caretaker family of four were the only inhabitants

# Swains Island

Freshwater/brackish water lake



abundant coral but very few large fish

Ornate butterfly fish
feeding on coral polyps

**The 2002 marine surveys were perhaps the first for the island**

**Crown-of-thorns sea stars feeding on corals**

**discovery of the rare blue coral, a new range extension**

*Heliopora coerulea*

# Swains Island: corals

- only 40 species and 17 genera of corals, reported at 10 sites, with only 5 of the genera common
- very high coral abundance in all shallow habitats
- no very large corals above a depth of 20m
- our observations & the island residents confirmed a mass coral bleac event in 1994, coinciding with that at Rose
- tsunami waves and a hurricane also struck Swains in the early 1990's according to the residents
- coral communities are healthy and recolonizing rapidly

# Wake Atoll (U.S.)

**total reef area= 7,907 ac**
**total land area= 1,828 ac**


- geologically, Wake is the northern-most of the Marshall Islands

- it is also one of the most isolated atolls in the Pacific, 300 nm north of Bokaak (Republic of Marshall Is.)

# Wake Atoll:

- U.S. military base since WW II
- refueling stop for trans-pacific aircraft
- missile test range in recent years
- belongs to the Dept. of interior

Wake saw action during WW II

arid climate and vegetation

Lagoon shoreline, Wake I.

sunken fuel barge at Wake, 1979

# Wake Atoll: only limited reef studies to date

- 1999 reef survey by USFWS & NMFS
- brief 1979 Army Corps of Eng. survey


- 41 species and 21 genera of corals
- less than half of the species at larger neighboring Bokaak Atoll

- modest coral bleaching Reported in May 1979

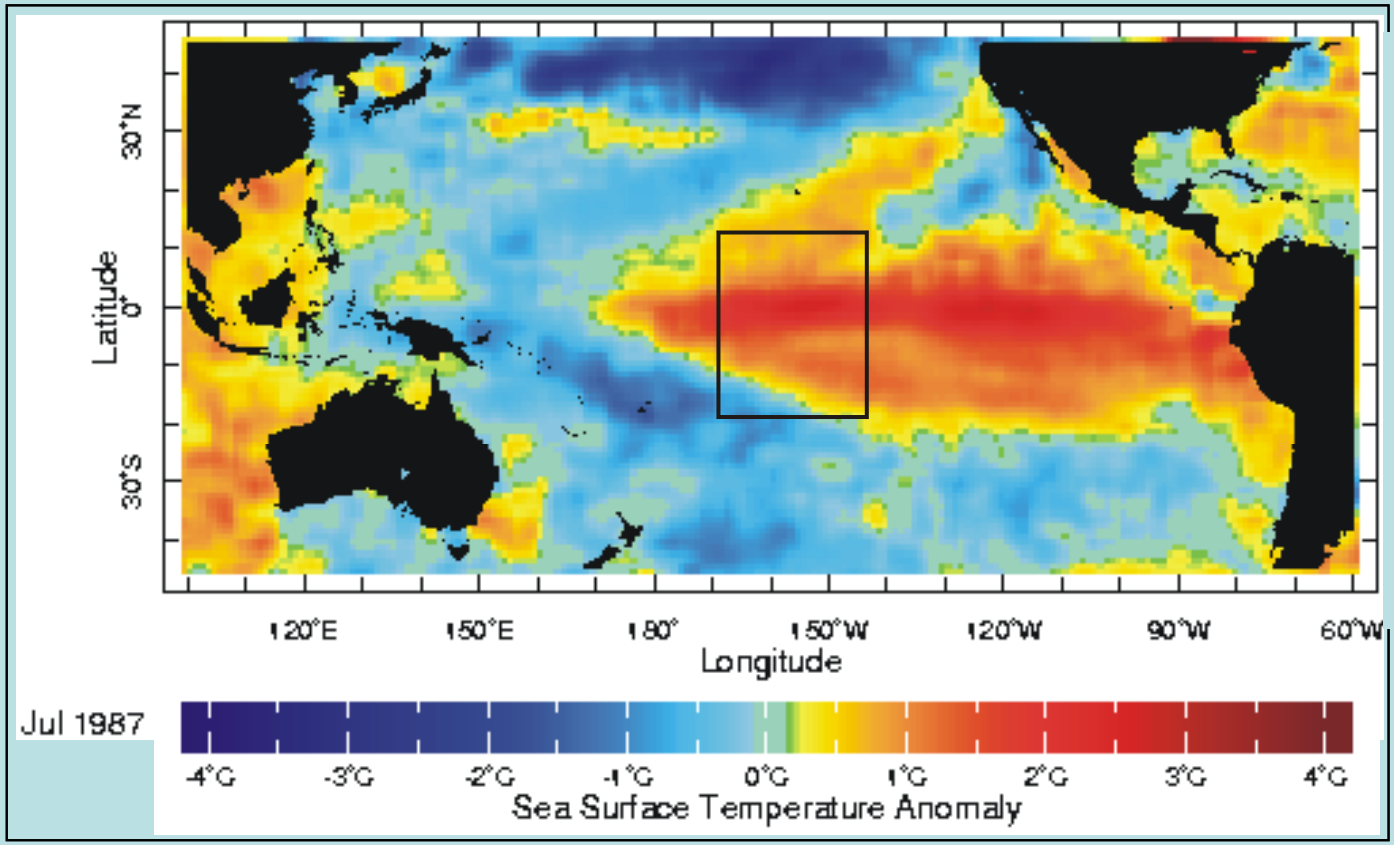
bleached *Pocillopora*,

# Coral Bleaching in the remote U.S. Pacific Islands:

- bleaching has been reported or deduced at all PRIAs, except Johnston and Kingman Reef, where information is sketchy
- bleaching has occurred at atolls or reef islands closest and furthest from the Equator between 1997-2002 in the Pacific
- management response has focused on inventory, assessment and monitoring- all are critical
- impacts of bleaching has been most severe at atolls also experiencing catastrophic anthropogenic stress (Palmyra & Rose), & restoration of reefs is being pursued

coral bleaching @ Midway, Dec 2002

# ENSO: El Nino Southern Oscillation



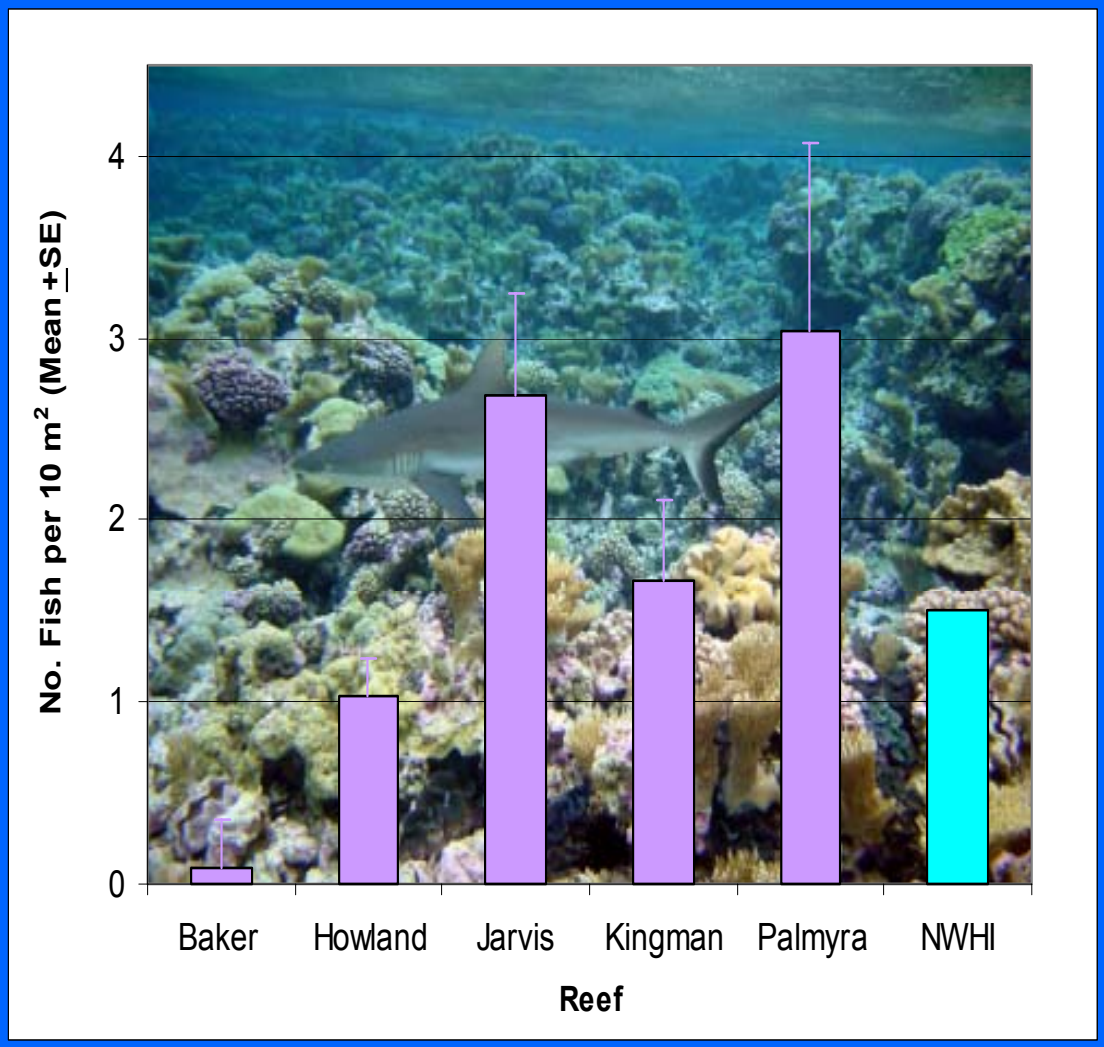

**The ENSO of 1997-98 probably led to mass bleaching at most of the equatorial NWRs, especially Jarvis Howland, Baker & Palmyra National Wildlife Refuges.**

Higher SST + Climate Change Implications for Line Islands:

- high potential for bleaching (Jarvis 97-98)
- need to **maintain maximum resilience** through ensuring high species and habitat biodiversity.

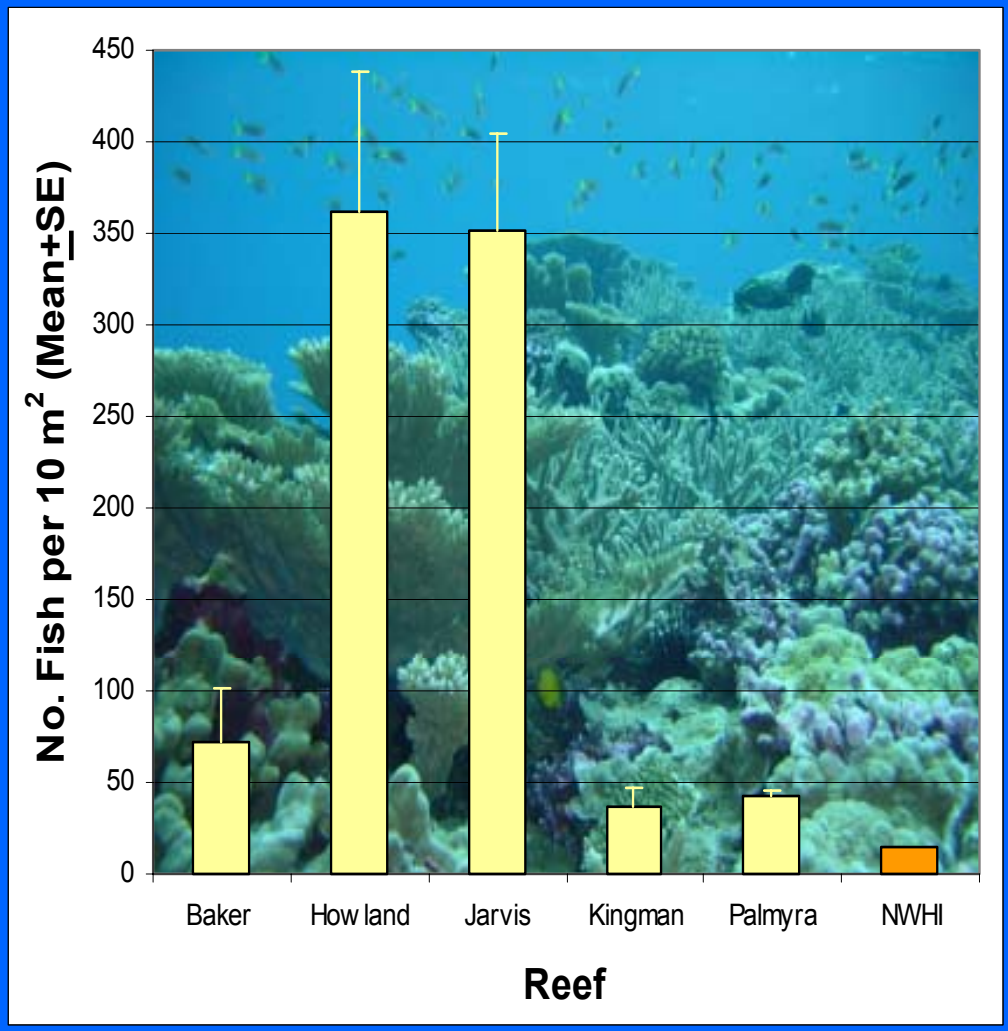
slide credit: NOAA & Meriwether Wilson

# Large Fish Density




- **Moderately large fish (> 20 cm TL) were equal or up to twice as abundant at most Line & Phoenix Island reefs than in NWHI**

# Small Fish Density




- **Densities of small fish (≤ 20 cm TL) were 3-25x higher than in the NWHI**

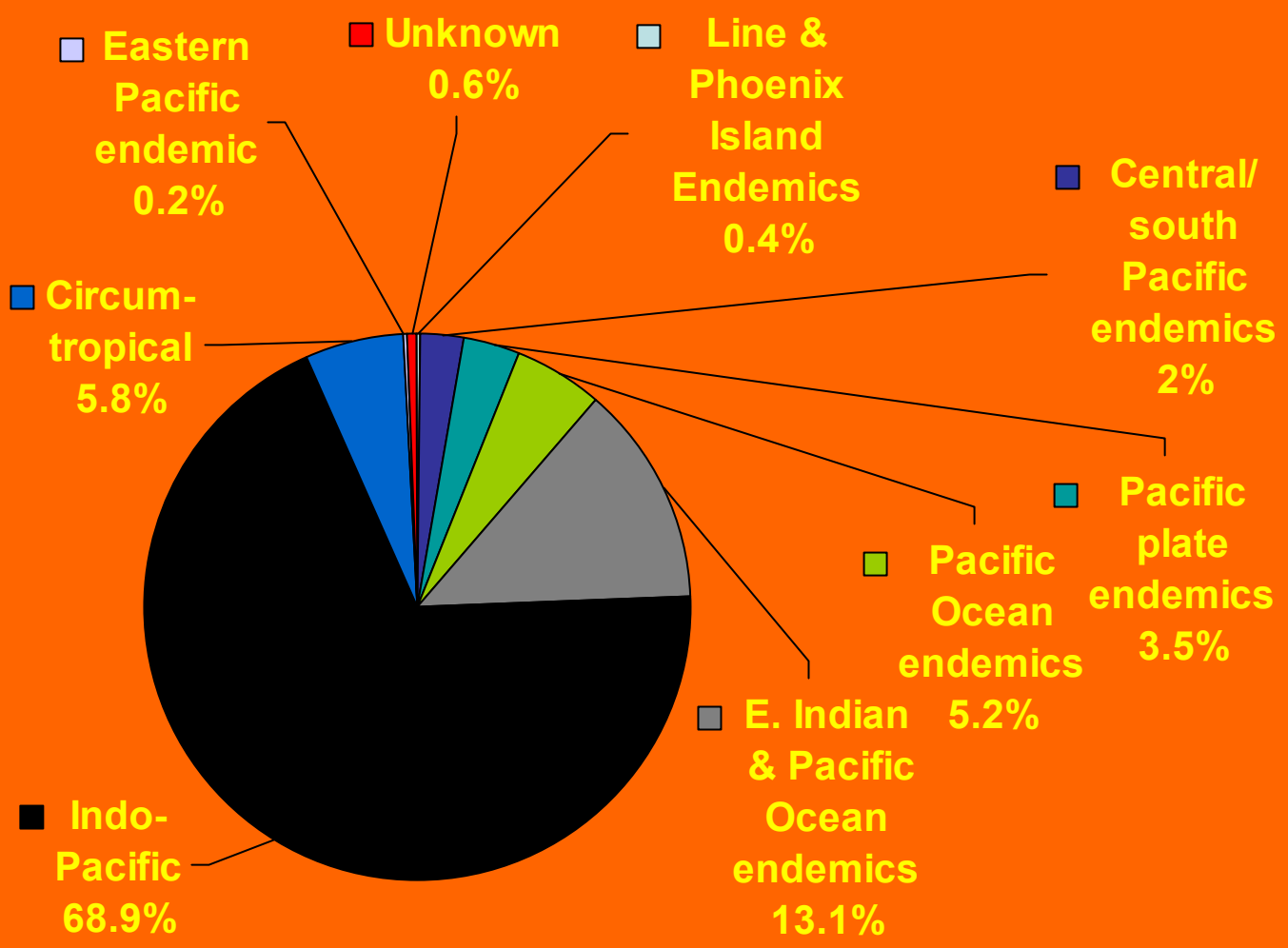
# Preliminary Conclusions: Equatorial Islands Reef Fish Surveys

- Baseline (from 2000-01) expanded for all reefs
- Numerical density of large fish ≥ NWHI; small fish density also higher (especially at upwelling reefs)
- Howland & Jarvis (upwelling reefs) had the highest densities of grouper, pygmy angels and planktivores
- Pygmy angels common at all reefs (except flames at Kingman)
- Maori wrasse common at Palmyra, but not sighted at upwelling reefs
- Predators were relatively twice as numerous at the northern Line Island reefs (non-upwelling)
- At Baker highest planktivore densities on W (upwelling side); (further analysis- expect to see same at Howland & Jarvis)

# Biogeographic patterns for reef fishes at these islands

**The majority of species have Indo-Pacific distributions.**

**Species with restricted distributions are important for assessing reef ecosystem health.**



# How many species did we find at each island?

**Palmyra has the most for both fish & corals.**

**Baker with less than Howland for both corals & fish.**

**Kingman with the least for fish & second most for corals**

**Oceanography & fishery catch data may understand these differences.**