DR. FABRY: THANK YOU. IT’S A REAL PLEASURE TO BE HERE.

TODAY I'M GOING TO TALK ABOUT THE POSSIBLE CONSEQUENCES OF GLOBAL WARMING AND OCEAN ACIDIFICATION ON MARINE ECOSYSTEMS.

WE KNOW THAT THE OCEAN IS GETTING WARMER, AND IT'S TAKING UP MORE ANTHROPOGENIC CO2. THIS CLIMATE FORCING HAS OTHER ENVIRONMENTAL EFFECTS, PARTICULARLY ON THE UPPER WATER COLUMN WHICH IN THE FUTURE WILL BECOME MORE STRATIFIED, WILL HAVE LOWER NUTRIENT AVAILABILITY, DECREASED OXYGEN, LOWER PH, LOWER CARBONATE ION CONCENTRATION, AND A LOWER CARBONATE SATURATION STATE. THIS ENVIRONMENTAL FORCING WILL HAVE EFFECTS ON THE PHYSIOLOGICAL PROCESSES OF ORGANISMS; PHYSIOLOGICAL PROCESSES SUCH AS PHOTOSYNTHESIS, CALCIFICATION, NITROGEN FIXATION, GROWTH AND REPRODUCTION, AND ULTIMATELY THE FITNESS AND THE SURVIVAL OF THE ORGANISM. THESE PHYSIOLOGICAL EFFECTS THEN CAN PROPAGATE UP TO THE ECOSYSTEM LEVEL, AND THERE CAN BE ECOSYSTEM IMPACTS SUCH AS POTENTIAL CHANGES IN THE OVERALL PRODUCTIVITY OF A REGION, CHANGES IN SPECIES SUCCESSION, ALTERATIONS TO FOOD WEBS, SHIFTS IN SPECIES ABUNDANCES AND THEIR DISTRIBUTIONS, AND ALSO IMPACTS ON BIOGEOCHEMICAL CYCLING. THESE IN TURN CAN FEED BACK TO CLIMATE.

RIGHT NOW THE UNCERTAINTIES ARE VERY GREAT. WE DON'T HAVE A VERY CLEAR MECHANISTIC UNDERSTANDING, SO WE DEFINITELY NEED MORE RESEARCH. BUT TODAY I'M GOING TO GIVE YOU A FEW EXAMPLES OF HOW ECOSYSTEMS MAY BE IMPACTED IN THE FUTURE UNDER CLIMATE CHANGE.

FIRST, I'LL TALK A LITTLE BIT ABOUT THE DECLINE IN ANTARCTIC KRILL, THEN I'LL DISCUSS CORAL BLEACHING AND OCEAN ACIDIFICATION, AND I'LL END WITH A FEW COMMENTS ON MITIGATION AND ADAPTATION.

SO LET'S START DOWN IN THE SOUTHERN OCEAN WITH KRILL. THIS IS THE WORK OF ARGUS ATKINSON, WHO MONITORED A ZOOPLANKTON POPULATION IN THE ATLANTIC SECTOR OF ANTARCTICA. THE WESTERN PENINSULA OF ANTARCTICA IS ONE OF THE FASTEST WARMING REGIONS ON THE EARTH.

IN THIS GRAPH, YOU CAN SEE THAT THE CONCENTRATION OF KRILL HAS DECREASED OVER THE LAST 25 YEARS. THERE HAS BEEN ABOUT A 50-PERCENT DECREASE IN KRILL ABUNDANCE IN MANY AREAS, AND IT SEEMS TO BE CORRELATED WITH A LOSS OF WINTER ICE EXTENT IN THE WESTERN PENINSULA. AT THE SAME TIME THAT YOU SEE THESE DECREASES IN KRILL POPULATIONS, YOU ALSO SEE INCREASES IN SALPS, ANOTHER TYPE OF HERBIVOROUS ZOOPLANKTON.

SOME PEOPLE HAVE SUGGESTED THAT WE MAY SEE A REGIME SHIFT IN THE FUTURE FROM A KRILL-DOMINATED SYSTEM TO ONE THAT IS DOMINATED BY SALPS. SUCH A CHANGE HAS IMPLICATIONS FOR ANTARCTIC FOOD WEBS BECAUSE KRILL ARE REALLY AT THE CENTER OF ANTARCTIC FOOD WEBS. KRILL ARE NORMALLY VERY ABUNDANT, THEY ARE A VERY NUTRITIOUS FOOD SOURCE, AND THEY ARE PREY FOR A NUMBER OF HIGHER TROPHIC LEVELS, INCLUDING FISH, PENGUINS, AND WHALES; EVEN THE CRAB-EATER SEAL ACTUALLY EATS KRILL, NOT CRABS.

HOWEVER, IF WE GET A SHIFT IN THE REGIME FROM A KRILL-DOMINATED SYSTEM TO ONE DOMINATED BY SALPS, THE FOOD WEB WOULD CHANGE. SALPS ARE GELATINOUS ORGANISMS. THEIR BODIES ARE ABOUT 96 PERCENT WATER AND THEY ARE A VERY CARBON-POOR FOOD SOURCE. THEY'RE GENERALLY NOT THE PREFERRED PREY FOR ANY ORGANISM IN A HIGHER TROPHIC LEVEL, AND THEY DON'T LEAD TO HIGHLY PRODUCTIVE FISHERIES. THEY HAVE VERY FAST GENERATION TIMES, SO YOU CAN GET A SALP SWARM IN NO TIME AT ALL. SALPS ARE GENERALLY ASSOCIATED WITH LOWER LATITUDE SYSTEMS RATHER THAN AROUND THE ANTARCTIC WESTERN PENINSULA. AS A CONSEQUENCE, DETERMINING WHETHER A REGIME SHIFT IS TAKING PLACE, FROM A KRILL-DOMINATED SYSTEM TO A SALP-DOMINATED SYSTEM, IS AN AREA OF ACTIVE RESEARCH.

LET'S MOVE ON NOW AND TALK ABOUT CORAL BLEACHING. HEALTHY CORALS, SHOWN HERE, ARE RICH IN COLOR. THERE IS A SYMBIOSIS BETWEEN THE CORAL POLYP, WHICH IS AN ANIMAL, AND THE ZOOXANTHELLAE, WHICH ARE PHOTOSYNTHETIC ALGAE THAT LIVE WITHIN THE TISSUES OF THE CORAL POLYP. IF THE SUMMERTIME MAXIMUM TEMPERATURE IS EXCEEDED, THE

CORAL POLYP CAN EXPEL ITS ZOOXANTHELLAE AND LEAVE THE CORAL WHITE OR BLEACHED. THE CORAL CAN SURVIVE IN THIS STATE FOR A NUMBER OF WEEKS, BUT IF THE ZOOXANTHELLAE DON'T RETURN TO THE CORALS, THEN CORAL MORTALITY WILL ULTIMATELY RESULT.

CORAL BLEACHING WAS FIRST OBSERVED IN THE LATE 1970S, AND IT'S BEEN INCREASING IN ITS OCCURRENCE EVER SINCE THEN. WHAT YOU SEE HERE IS A VERY EXTENSIVE, HEALTHY REEF IN 1995 OFF BELIZE; AND IN 1998, SHORTLY AFTER THE '97-'98 EL NINO, WHICH I THINK IS ONE OF THE STRONGEST, IF NOT THE STRONGEST, EL NINO ON RECORD, YOU SEE VERY STRONG EVIDENCE OF MASSIVE BLEACHING IN THE CORALS. WHEN THE INVESTIGATORS WENT BACK IN 1999, THEY FOUND THE CORALS HAD DIED, AND THEY HAD BEEN REPLACED BY GREEN MACROALGAE. THIS CORAL REEF SYSTEM IN BELIZE ESSENTIALLY WAS DECIMATED.

NOAA HAS DEVELOPED INDICES OF CORAL BLEACHING BY MAPPING THE SEA SURFACE TEMPERATURE ANOMALIES FROM SATELLITE DATA. A ONE DEGREE HEATING WEEK, DHW, IS WHEN THE TEMPERATURE OF THE WATER IS 1 DEGREE C ABOVE THE MAXIMUM MONTHLY MEAN FOR 1 WEEK. WHEN YOU HAVE 4-DEGREE HEATING WEEKS, SHOWN IN THE GREEN COLOR, YOU CAN EXPECT CORAL BLEACHING TO OCCUR. HOWEVER, IF THE TEMPERATURES STAY ELEVATED AND YOU HAVE 8-OR-MORE-DEGREE HEATING WEEKS, THEN BLEACHING AND MORTALITY ARE EXPECTED. THAT IS DESIGNATED BY THE YELLOW, GOING INTO THE PINK AND THE PURPLE COLOR.

THIS IS A VIDEO FROM THE CARIBBEAN AND THE GULF OF MEXICO FROM 1985 TO 2005. YOU CAN SEE THAT IN THE EARLY YEARS, THERE WAS VERY LITTLE INCIDENCE OF DEGREE HEATING WEEKS. BUT IT INCREASES OVER TIME; AND THEN FINALLY IN 2005, THE EASTERN CARIBBEAN SEA WAS TREMENDOUSLY IMPACTED BY HIGH TEMPERATURES; AND THAT LED TO MASS MORTALITY OF NEARLY 40 PERCENT OF THE ENTIRE CORAL REEF ECOSYSTEM IN THE EASTERN CARIBBEAN. ALMOST 40 PERCENT OF THE ECOSYSTEM DIED IN A SINGLE YEAR.

LET'S MOVE ON AND TALK ABOUT OCEAN ACIDIFICATION. THE OCEANS ARE TAKING UP ANTHROPOGENIC CO2, AND THIS CHANGES SEAWATER CHEMISTRY, AS DICK EXPLAINED. A MODELING

STUDY BY CALDEIRA AND WICKETT PROJECTED THAT BY THE END OF THIS CENTURY, BY 2100, THE MEAN PH OF THE SURFACE WATER COULD DROP BY 0.3 TO 0.5 OF A PH UNIT RELATIVE TO THE PRE-INDUSTRIAL VALUE. THIS RATE OF CHANGE IS SIGNIFICANT. IT IS PROBABLY ABOUT A HUNDRED TIMES FASTER THAN THAT WHICH OCCURRED AT THE END OF THE RECENT ICE AGES, AND IT IS PROBABLY TOO FAST TO ALLOW CHANGES IN OCEAN CHEMISTRY TO BE BUFFERED BY THE DISSOLUTION OF CALCIUM CARBONATE SEDIMENTS ON THE SEA FLOOR.

WHAT ARE THE IMPACTS OF OCEAN ACIDIFICATION? WE KNOW THE MOST ABOUT THE RESPONSE OF CALCIFIERS TO OCEAN ACIDIFICATION. THESE ARE THE THREE MAJOR GROUPS OF PLANKTONIC CALCIFIERS. AT THE TOP ARE COCCOLITHOPHORES.

THESE ARE SINGLE-CELLED ALGAE. THEY PHOTOSYNTHESIZE, AND THE CELL SURFACE IS COVERED WITH CALCIUM CARBONATE PLATES.

THE PHOTO BELOW IS A FORAMINIFERAN. THIS IS A PROTIST, ESSENTIALLY LIKE A SHELLED AMOEBA.

AND THEN SHOWN BELOW THAT ARE THE PTEROPODS, PLANKTONIC SNAILS THAT SECRETE SHELLS MADE OF ARAGONITE, THE SAME TYPE OF CALCIUM CARBONATE THAT CORALS PRECIPITATE.

IN ADDITION TO THESE THREE MAJOR PLANKTONIC GROUPS, THERE IS ALSO A DIVERSE SUITE OF BENTHIC CALCIFIERS: THE CORALS THAT WE'VE ALREADY TALKED ABOUT INCLUDING HARD CORALS AND SOFT CORALS; MANY DIFFERENT TYPES OF MOLLUSCS INCLUDING GASTROPODS, AND BIVALVES - MANY OF THESE ARE VERY IMPORTANT TO COMMERCIAL FISHERIES AND ALSO ARE IMPORTANT IN AQUACULTURE WORLDWIDE. OTHER BENTHIC CALCIFIERS INCLUDE SEA URCHINS AND CORALLINE RED ALGAE WHICH SECRETE CALCIUM CARBONATE IN THE FORM OF HIGH-MAGNESIUM CALCITE. THIS TYPE OF CALCIUM CARBONATE IS VERY SOLUBLE IN SEAWATER. IN ADDITION, SOME CRUSTACEANS, THE DECAPODS SUCH AS CRABS AND LOBSTERS, HAVE VERY HARD SHELLS WHICH CONTAIN A CALCIFIED LAYER. MANY OF THESE BENTHIC ORGANISMS HAVE PLANKTONIC LARVAL STAGES THAT ALSO CALCIFY. WE THINK THAT PLANKTONIC LARVAL STAGES COULD BE PARTICULARLY VULNERABLE TO

DECREASING PH IN THE OCEANS.

THUS FAR, CORAL REEFS HAVE BEEN MOST STUDIED IN EXPERIMENTS INVESTIGATING THE IMPACTS OF OCEAN ACIDIFICATION.

THESE DATA ARE FROM THE WORK OF CHRIS LANGDON, WHO DID A NUMBER OF EXPERIMENTS WITH CORALS IN THE LAB AND ALSO IN THE BIOSPHERE 2 MESOCOSM. HERE HE HAS PLOTTED THE RESPONSE OF 12 DIFFERENT SPECIES OF REEF-CALCIFYING ORGANISMS AS A FUNCTION OF THE CARBONATE ION CONCENTRATION, SHOWN ON THE X-AXIS.

WE'VE ALSO PLOTTED ON THIS GRAPH THE CORRESPONDING ATMOSPHERIC CO2 CONCENTRATION. WHAT WE FIND IS THAT AT HIGH CARBONATE ION CONCENTRATIONS, REEF ORGANISMS HAVE HEALTHY, VERY GOOD CALCIFICATION RATES. CALCIFICATION RATES DECLINE LINEARLY WITH DECREASING CARBONATE ION CONCENTRATION. WHEN THE CARBONATE CONCENTRATION DECLINES TO ABOUT 150 MICROMOLAR, THEN NET DISSOLUTION OCCURS. NOW, THIS NUMBER IS A LITTLE UNCERTAIN. NET DISSOLUTION MIGHT OCCUR AT SLIGHLY HIGHER OR LOWER CARBONATE ION CONCENTRATIONS, BUT WHEN IT DECLINES BELOW ABOUT 110 TO 150 MICROMOLAR, THESE DATA SUGGEST THAT NET DISSOLUTION OF THE REEF WILL RESULT. AND 150 MICROMOLAR CORRESPONDS TO AN ATMOSPHERIC CO2 CONCENTRATION OF ABOUT 550 PPM.

THIS IS THE CLEAREST EXAMPLE THAT WE HAVE OF A TIPPING POINT IN MARINE SYSTEMS. AND IT BEGS THE QUESTION: CAN CORALS SURVIVE DECREASED CARBONATE ION CONCENTRATION AND LOWER PH?

IN A RECENT STUDY, FINE & TCHERNOV GREW TWO DIFFERENT SPECIES OF CORALS IN CORROSIVE WATER, THE PH WAS ABOUT 7.3 TO 7.6, FOR A YEAR. THE CORALS STARTED LIKE THIS -- AND AFTER A MONTH IN THAT CORROSIVE SEAWATER, THE SKELETON COMPLETELY DISSOLVED, AND THE CORAL COLONY DISASSOCIATED INTO INDIVIDUAL POLYPS, WHICH THEN LOOKED VERY MUCH LIKE ANEMONES. AFTER 11 MONTHS, FINE AND TCHERNOV PUT THE POLYPS BACK INTO NORMAL SEAWATER; AND THE POLYPS STARTED TO RECALCIFY AND REAGGREGATE INTO A COLONY.

THESE RESULTS ARE VERY INTERESTING. THE CORALS WERE NOT ABLE TO CALCIFY AT LOW PH, BUT THEY DID SURVIVE. THIS STUDY WAS DONE IN THE LAB. WHAT DOES IT MEAN FOR THE FIELD? IN THIS LAB STUDY, THERE WAS NO PREDATION. IF WE CAN ASSUME THAT A CARBONATE SKELETON PROVIDES SOME BENEFIT TO THE ORGANISM, SOME PROTECTION FROM PREDATORS, THESE NAKED POLYPS THAT RESULTED IN THE THE LAB PROBABLY WOULD NOT SURVIVE OUT IN THE OPEN IN THE FIELD.

THEY WOULD HAVE TO LIVE CRYPTICALLY IN CREVICES, HIDDEN FROM PREDATORS, OR THEY WOULD BE EATEN. IN ADDITION, THE ABSENCE OF CORAL CALCIFICATION MEANS THERE IS THE LOSS OF THAT THREE-DIMENSIONAL REEF STRUCTURE THAT IS SO IMPORTANT AND ENABLES REEF SYSTEMS TO HAVE VERY HIGH BIODIVERSITY. FINALLY, IN THE ABSENCE OF CORAL CALCIFICATION, YOU WOULD ALSO GET CHANGES IN THE ECOSYSTEM SERVICES THAT REEFS SUPPLY.

LET'S TURN NOW TO THE PLANKTON, WHERE CALCIFICATION ALSO PLAYS A VERY IMPORTANT ROLE. THIS IS FROM A LANDMARK STUDY BY ULF RIEBESELL AND HIS COLLEAGUES. THEY LOOKED AT THE COCCOLITHOPHORES. THESE ARE THE SINGLE-CELLED ALGAE THAT PHOTOSYNTHESIZE AND MAKE CALCIUM CARBONATE PLATES. THESE ARE TWO DIFFERENT SPECIES OF BLOOM-FORMING COCCOLITHOPHORES. THEY'RE VERY ABUNDANT, AND THE BLOOMS THAT THESE SPECIES FORM CAN BE SEEN IN SATELLITE IMAGES.   WHEN RIEBESELL AND HIS CO-WORKERS GREW THESE SPECIES IN THE LAB UNDER CONDITIONS OF ELEVATED CO2, THEY FOUND THAT CALCIFICATION DECREASED. THIS SPECIES, GEPHYROCAPSA OCEANICA, WAS PARTICULARLY SENSITIVE AND ITS CALCIFICATION RATE DECREASED BY ALMOST 50 PERCENT WHEN PCO2 WAS ELEVATED TO 780-850 PPMV.

BUT NOT ALL COCCOLITHOPHORES RESPOND IN THE SAME WAY. TWO ADDITIONAL SPECIES HAVE BEEN INVESTIGATED TO DATE, AND ONE OF THESE SPECIES WAS NOT SENSITIVE TO

INCREASED PCO2. CURRENTLY, THAT SINGLE SPECIES OF COCCOLITHOPHORE IS THE ONLY EXAMPLE WE HAVE OF A CALCIFYING ORGANISM THAT IS NOT SENSITIVE TO ELEVATED PCO2. BUT I NEED TO TELL YOU THAT WE HAVE JUST SCRATCHED THE SURFACE. WE HAVE INVESTIGATED SO FEW SPECIES, SO FEW TAXA, THAT WE CAN'T MAKE GENERALITIES AT THIS POINT.

THE PTEROPODS ARE ANOTHER IMPORTANT PRODUCER OF CALCIUM CARBONATE IN THE PLANKTON, AND THEY ARE WIDELY DISTRIBUTED THROUGHOUT THE WORLD'S OCEANS. THEY ARE VERY ABUNDANT AT HIGH LATITUDES. IN POLAR AND SUBPOLAR REGIONS, THEIR POPULATIONS CAN OCCUR IN VERY HIGH NUMBERS, WITH DENSITIES GREATER THAN 1000 INDIVIDUALS PER CUBIC METER. WHEN PTEROPODS OCCUR IN SUCH HIGH NUMBERS, THEY ARE GOING TO BE AN IMPORTANT FOOD SOURCE FOR A VARIETY OF DIFFERENT PREDATORS. DATA FROM THE NORTH PACIFIC SUGGEST THAT PTEROPODS MAY BE VERY IMPORTANT IN SOME YEARS TO THE RECRUITMENT AND ADULT BIOMASS OF SALMON, POLLOCK, AND SOME OTHER COMMERCIALLY IMPORTANT FISH. ON REGIONAL SCALES, PTEROPODS MAY ALSO AFFECT THE GEOCHEMICAL CYCLES OF CARBON AND SULFUR, AS THEY CONCENTRATE DIMETHYL SULFIDE. WHEN WE PUT LIVE PTEROPODS IN SEAWATER WITH LOWER CALCIUM CARBONATE ION CONCENTRATION - A CONCENTRATION THAT WOULD CORRESPOND TO THE SEAWATER CONDITIONS THAT ARE PROJECTED TO OCCUR AT HIGH LATITUDES BY THE YEAR 2100 - THE SHELLS OF THE ANIMALS STARTED TO DISSOLVE WITHIN 48 HOURS. THE ANIMALS WERE STILL ACTIVELY SWIMMING, BUT THEIR SHELLS WERE DISSOLVING. AT LEAST IN THE SHORT TERM, IT DOESN'T APPEAR THAT PTEROPODS HAVE ANY MECHANISMS TO PROTECT THEM FROM DISSOLUTION. THEIR SHELLS ARE VERY THIN, ON THE ORDER OF 7 MICROMETERS THICK, AND THEY WILL DISSOLVE RAPIDLY UNDER CORROSIVE CONDITIONS.

IN THE HIGH LATITUDES, PTEROPODS APPEAR TO HAVE

VERY LONG GENERATION TIMES. THEY MAY HAVE A GENERATION TIME OF ABOUT 1 TO 2 YEARS. AS A CONSEQUENCE, HIGH LATITUDE PTEROPODS DO NOT HAVE MANY OPPORTUNITIES TO DEVELOP NEW MECHANISMS OF COPING WITH OCEAN ACIDIFICATION BEFORE 2100.

THERE IS ADDITIONAL EVIDENCE FOR OTHER IMPACTS OF OCEAN ACIDIFICATION ON ECOSYSTEMS AND ORGANISMS. STUDIES REVEAL THAT THERE ARE ADVERSE EFFECTS ON REPRODUCTIVE SUCCESS, FOR EXAMPLE, IN SEA URCHINS, BIVALVES, COPEPODS AND FISH LARVAE. OTHER STUDIES INDICATE THERE IS REDUCED GROWTH IN ADULTS, APART FROM THE CALCIFICATION EFFECTS THAT WE'VE JUST DISCUSSED. WE SEE REDUCED GROWTH IN ADULT SEA URCHINS AND BIVALVES, FOR EXAMPLE.

ELEVATED CO2 CAN ALSO IMPAIR THE OXYGEN TRANSPORT OF THE BLOOD PIGMENT IN SQUID. HIGH PCO2 ALSO APPEARS TO REDUCE THE SCOPE OF ACTIVITY IN SQUIDS.

THERE ARE SEVERAL RECENT PAPERS THAT REPORT INCREASED RATES OF NITROGEN FIXATION UNDER HIGH CO2 CONDITIONS, AND THIS COULD HAVE VERY SWEEPING, LARGE-SCALE CHANGES IN ALGAL ABUNDANCE AND NUTRIENT LIMITATION IN SOME SUBTROPICAL AREAS, WHICH COULD RESULT IN MAJOR REORGANIZATION OF SUCH ECOSYSTEMS.

MOVING ON TO MITIGATION, AS WE HAVE ALL HEARD DURING THE LAST TWO DAYS, WE NEED TO DECREASE CO2 EMISSIONS.

OTHER MITIGATION STRATEGIES THAT ARE FOCUSED ON THE OCEAN INCLUDE IRON FERTILIZATION, DIRECT INJECTION OF CO2, AND SEAWATER ELECTROLYSIS. THERE ARE A FEW OTHER IDEAS OUT THERE, AND ALL OF THESE OPTIONS HAVE PROS AND CONS ASSOCIATED WITH THEM.

THERE IS THIS SENSE OF URGENCY. SOME PEOPLE HAVE SAID WE HAVE ONLY A 10-TO-20-YEAR WINDOW TO MAKE SUBSTANTIAL CHANGES. THAT ESTIMATE WAS IN THE STERN REPORT AND WAS ALSO SUGGESTED BY JIM HANSEN IN A RECENT NAS PAPER.

NOW, WHAT ABOUT ADAPTATION AND COPING STRATEGIES? THE BEST EXAMPLE WE HAVE

IS THE "REEF MANAGER'S GUIDE TO CORAL BLEACHING." THIS JUST CAME OUT IN THE LAST YEAR AND IS THE PRODUCT OF A COLLABORATION BETWEEN NOAA, THE EPA, AND THE AUSTRALIA GREAT BARRIER REEF PARK AUTHORITY. THIS GUIDE PROVIDES CORAL REEF MANAGERS WITH SOME STRATEGIES THAT THEY CAN USE TO TRY TO PROTECT THEIR REEFS DURING THOSE HIGH-DEGREE HEATING WEEKS, THOSE CONTINUOUS WEEKS OF ELEVATED TEMPERATURE. ONE OF THE SUGGESTIONS IS TO PUT OUT SHADE CLOTH OVER CERTAIN AREAS OF THE REEF. OBVIOUSLY, THIS IS A VERY SMALL-SCALE, LOCALIZED COPING STRATEGY.

OTHER SUGGESTIONS INVOLVE TRYING TO DECREASE OR LIMIT OTHER STRESSORS, SUCH AS FISHING OR HUMAN ACCESS TO THAT REEF. IN OTHER WORDS, TRY TO CONTROL WHAT YOU CAN TO PROVIDE THE CORALS A BETTER CHANCE OF SURVIVING THOSE ELEVATED TEMPERATURE PERIODS.

ANOTHER IDEA THAT HAS BEEN SUGGESTED IS TO REAR THE POTENTIALLY VULNERABLE JUVENILE STAGES OF ORGANISMS UNDER CONTROLLED CONDITIONS, IN A LABORATORY OR AN AQUACULTURE FACILITY, FOR EXAMPLE; AND THEN AFTER THE ORGANISMS HAVE GROWN TO A LARGER SIZE THAT MAY BE MORE RESISTANT TO ELEVATED PCO2, YOU CAN RELEASE THEM IN THE FIELD.

ALSO, YOU COULD REPOPULATE IMPACTED AREAS WITH RESISTANT SPECIES.

NOW, THE PROBLEM WITH THESE LAST TWO IDEAS IS THAT THEY ARE MERELY SUGGESTIONS AT THIS TIME. WE DON'T HAVE ENOUGH INFORMATION OR A SUFFICIENT UNDERSTANDING OF THE IMPACTS AND THE MECHANISMS INVOLVED TO ACTUALLY DEVELOP EFFECTIVE COPING STRATEGIES AT THIS POINT. SO, AGAIN, RESEARCH IS CLEARLY REQUIRED.

WHERE SHOULD WE GO FROM HERE? IN MY VIEW, THERE ARE SEVERAL RESEARCH CHALLENGES AHEAD OF US. IF WE ARE TO MAKE SIGNIFICANT PROGRESS IN MANY AREAS, IT IS GOING TO REQUIRE MULTI-DISCIPLINARY AND INNOVATIVE APPROACHES. SOME OF THE PARTICULARLY DIFFICULT ISSUES THAT WILL NEED TO BE RESOLVED OVER THE LONG-TERM INCLUDE THE FOLLOWING.

FIRST, WE NEED TO DEVELOP METHODS TO

INVESTIGATE THE RESPONSE OF ORGANISMS THAT WE CAN'T MAINTAIN IN THE LAB. WE NEED TO BE ABLE TO INVESTIGATE THEM IN THE FIELD UNDER FIELD CONDITIONS. THIS INCLUDES ORGANISMS SUCH AS FORAMINIFERA, PTEROPODS, AND SQUID. WE CAN'T CULTURE THOSE IN THE LAB AND, TO DATE, WE HAVE ONLY BEEN ABLE TO DO VERY SHORT-TERM EXPERIMENTS. WHILE SUCH EXPERIMENTS PROVIDE VITAL DATA AND ARE CRITICAL TO CONDUCT AT THIS STAGE OF OCEAN ACIDIFICATION RESEARCH, WE ULTIMATELY WOULD WANT TO DO EXPERIMENTS WITH THE ADDED COMPLEXITIES AND THE DIVERSITY OF SPECIES AT MULTIPLE TROPHIC LEVELS THAT ARE PRESENT IN ECOSYSTEMS.

WE ALSO NEED TO IDENTIFY THE SUBLETHAL EFFECTS OF LONG-TERM, CHRONIC EXPOSURE TO ELEVATED PCO2. IF YOU'RE DOING A PERTURBATION EXPERIMENT, YOU'RE GOING TO PUT AN ORGANISM IN ELEVATED PCO2. EVEN IF YOU ACCLIMATE THE ORGANISM FOR A PERIOD OF WEEKS OR MONTHS, THAT'S STILL NOT WHAT'S GOING TO ACTUALLY HAPPEN IN THE FIELD OVER A PERIOD OF DECADES AND OVER THE NEXT CENTURY. THIS IS A BIG CHALLENGE. HOW CAN WE ADDRESS WHETHER SPECIES WILL BE ABLE TO ADAPT? HOW CAN WE DETERMINE THE CAPACITY OF A SPECIES TO ADAPT OVER TIME SCALES OF DECADES TO CENTURIES?

FINALLY, WE NEED TO BE ABLE TO DEVELOP A PREDICTIVE UNDERSTANDING OF FUTURE CHANGES TO ECOSYSTEMS SO THAT EFFECTIVE COPING STRATEGIES CAN BE DEVELOPED.

THANK YOU FOR YOUR ATTENTION.