DR. BUTLER: I THOUGHT I WOULD THROW MAYBE A DEVIL'S ADVOCATE QUESTION HERE AT VICTORIA; BUT THE OTHERS CAN ALL FEEL FREE -- MY NAME IS JIM BUTLER, BY THE WAY -- AND THE OTHERS CAN FEEL FREE TO JOIN IN ON THIS ONE.

BUT THE CHANGE OF ECOSYSTEMS, FOR THE MOST PART, LIFE IN THE OCEAN IS DRIVEN BY LIGHT EMISSIONS, WHATEVER IS AVAILABLE THERE. IT'S EVOLVED TO ADJUST

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TO WHAT THE STATE OF THE OCEAN IS RIGHT NOW.

I THINK YOU GAVE US A GOOD EXAMPLE OF HOW IT COULD EVOLVE BADLY WITH THE SALPS AND THE KRILL. IF THERE'S A CHANGE THERE AND YOU'RE LOSING YOUR KRILL, THE SALPS COME IN. THAT'S NOT A GOOD THING FOR THE ECOSYSTEM AS A WHOLE.

I THINK OF ORGANISMS IN THE OCEAN, ESPECIALLY THOSE IN THE OPEN OCEAN, AS A COMMUNITY; AND THAT COMMUNITY CHANGES ITS STRUCTURE WITH THE SEASONS, IT CHANGES ITS STRUCTURE WITH FRESHWATER FLOWS FROM SAY COASTAL WATERS, ET CETERA; AND IT ADJUSTS, IT ADAPTS, IT MAKES IT WORK.

SO IS THERE ANY INDICATION THAT WE'RE LIKELY -- I MEAN, YOU HAVE GIVEN QUITE A FEW EXAMPLES HERE FROM THE CALCIFICATION-REMOVING OF THESE CALCIFIER ORGANISMS -- BUT THAT THEY MIGHT NOT BE SUCCEEDED BY OTHER ORGANISMS THAT WOULD BE EQUALLY GOOD FOR THE FOOD CHAIN?

DR. FABRY: WELL, I THINK YOU'RE RIGHT THAT THE OCEANS AREN'T GOING TO END, AND LIFE IN THE OCEANS ISN'T GOING TO END, BUT IT IS CERTAINLY GOING TO BE DIFFERENT. AND THE RATE OF CHANGE IS A CRITICAL POINT HERE. IT IS HAPPENING MUCH FASTER THAN WHAT WE THINK HAPPENED IN THE PAST GEOLOGIC TIME, AND I THINK JIM ZACHOS IS GOING TO BE TALKING

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ABOUT THAT IN GREATER DETAIL. BUT FOR A CORAL REEF, YOU NEED THAT 3-DIMENSIONAL STRUCTURE. THEY'RE ECOSYSTEM ENGINEERS FOR MANY OTHER SPECIES TO LIVE THERE, AND THE EXAMPLE I SHOWED OFF BELIZE, THE CORALS WERE ACTUALLY REPLACED BY MACROALGAE. WELL, YOU'RE NOT GOING TO HAVE THE FISH THERE. YOU'RE NOT GOING TO HAVE ALL THE GREAT BIODIVERSITY OF A REEF. SO THAT WOULD DEFINITELY CHANGE.

DR. FEELY: JUST ONE FACTOR TO KEEP IN MIND, FOR EXAMPLE, AS MUCH AS 30 PERCENT OR MORE OF FISHERIES ORGANISMS SPEND SOME TIME IN THEIR LIFE WITHIN THE CORAL REEF SYSTEMS. SO IF, IN FACT, WE HAVE A GLOBAL CHANGE IN THE CORAL REEF SYSTEMS, IT MAY HAVE A SIGNIFICANT IMPACT ON ONE OF OUR MAJOR FISHERIES.

ANOTHER POINT TO MAKE IS THROUGHOUT THE GEOLOGICAL RECORD, THERE HAS BEEN ACIDIFICATION EVENTS THAT HAVE TAKEN PLACE IN THE PAST, WHICH HAVE CAUSED THE EXTINCTION OF AS MUCH AS 97 PERCENT OF THE CORAL REEFS ORGANISMS IN THE PAST; FOR EXAMPLE, THE JURASSIC KT BOUNDARY; AND THE WAY THEY RETURNED IS BY EVOLUTION OF A NEW CORAL REEF SPECIES.

SO WE'RE TALKING ABOUT CONDITIONS THAT ARE UNPRECEDENTED IN GEOLOGICAL HISTORY AND A TRAJECTORY THAT IS LEADING US TOWARDS SIMILAR TYPES OF

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LARGE-SCALE CHANGES IN OUR OCEAN ECOSYSTEMS.

DR. DONEY: AND, JIM, I JUST WANT TO FINISH UP. YOU SAID, WHAT'S GOOD FOR THE OCEAN ECOSYSTEM. AND THAT'S SOMEWHAT OF A LOADED QUESTION. IT REALLY DEPENDS UPON YOUR PERSPECTIVE. AND IF YOU REMEMBER DAVE'S TALK THIS MORNING ABOUT AGRICULTURE, ONE WAY OF LOOKING AT IT IS THE ECOSYSTEM SERVICES: WHAT ARE THE SOCIETIES CURRENTLY DEPENDENT UPON USING THE ECOSYSTEMS FOR?

SO EVEN IF IN A MEASURE OF GLOBAL PRODUCTIVITY, GLOBAL PRODUCTIVITY STAYS THE SAME, WHAT YOU'RE GOING TO SEE IS A RESHUFFLING OF WHERE ORGANISMS ARE AND A REDISTRIBUTION OF THE DIFFERENT TYPES OF ORGANISMS.

AND WHAT WE DON'T KNOW IS WE'RE ROLLING THE DICE. WE MAY FIND CERTAIN FISHERIES THAT BENEFIT, BUT WE MAY FIND A LOT OF FISHERIES THAT DECLINE.

AND THE QUESTION IS: ARE THERE HUMAN SOCIETIES THAT ARE DEPENDENT UPON THOSE ECOSYSTEM SERVICES, DEPENDENT UPON CORAL REEFS OR OTHER FISHERIES, OR EVEN ALSO CORAL REEFS FOR SHORELINE PROTECTION? ARE THEY GOING TO BE ABLE TO ADAPT TO THOSE CHANGES?

AND A LOT OF THESE FISHERIES ARE USED BY RELATIVELY POOR, DEVELOPING COUNTRIES, AND THAT'S

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WHERE MY CONCERN IS; THAT THEY WON'T BE ABLE TO ADAPT TO CHANGES IN THE ECOSYSTEM.

SO, YOU KNOW, IT IS PUTTING IT BACK TO YOU: WHAT DO YOU MEAN IS GOOD IN THE VALUE OF THAT?

DR. BUTLER: PUTTING IT BACK TO ME, I WOULD JUST SAY THAT I THINK YOU SAID IT VERY WELL; THAT THE ECOSYSTEMS THAT WILL EVOLVE, WE DON'T KNOW WHAT THEY'RE GOING TO BE AND HOW WELL THEY WILL SERVICE. BUT I WONDER HOW MUCH OF THAT WOULD HAPPEN, HOW FAST, AND WOULD WE BE ADAPTING AND ADJUSTING. IT SEEMS TO ME TO BE AN UNANSWERED QUESTION OVERHANGING THE ISSUE.

LIKE I SAID, IT WAS A DEVIL'S ADVOCATE QUESTION.

MR. KEELING: I'M RALPH KEELING FROM SCRIPPS.

MY ATTENDANCE HERE WAS OCCASIONALLY SPOTTY, SO I APOLOGIZE IF I MISSED SOMETHING ALONG THESE LINES: BUT IF THE CHANGE IN OCEAN PH CAUSES CHANGES IN CALCIFICATION AND CALCIUM CARBONATE DISSOLUTION. THIS SHOULD MANIFEST ITSELF AS A CHANGE IN OCEAN ALKALINITY. AND SO MY QUESTION PERTAINS TO THE STATUS OF THE OBSERVING SYSTEM FOR CHANGES IN OCEAN ALKALINITY. I'M AWARE THAT THERE ARE TIME SERIES THAT ARE TRACKING ALKALINITY AT BERMUDA AND HAWAII.

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BUT IT STRIKES ME THAT THOSE AREN'T THE PLACES WHERE

ONE MIGHT FIRST EXPECT TO SEE BIG CHANGES.
SO ARE WE PREPARED FOR LOOKING FOR THIS?
DR. FEELY: THAT'S AN EXCELLENT QUESTION, RALPH.
I'LL ANSWER IT THIS WAY: THERE IS AT LEAST ONE PAPER IN THE LITERATURE THAT HAS SUGGESTED THAT BASED ON CHANGES IN ALKALINITY FROM THE GEOSET TO THE PRESENT HAS SHOWN AN INCREASE IN ALKALINITY. THIS PAPER I THINK IS ONE OF THESE ISSUES WHERE DID WE REALLY MAKE THE ALKALINITY MEASUREMENTS DURING GEOSET GOOD ENOUGH TO REALLY UNEQUIVOCALLY KNOW THAT THESE ALKALINE CHANGES HAVE TAKEN PLACE. AND MY SUGGESTION RIGHT NOW IS THAT WE'RE UNCERTAIN ABOUT THAT.
I THINK THE GLOBAL CO2 SURVEYS THAT WE ARE REPEATING NOW, A REPEAT OF WHAT WE DID DURING THE 1990S, DOES PROVIDE US WITH THE HIGH-QUALITY MEASUREMENTS TO LOOK VERY CAREFULLY AT THE ALKALINITY CHANGES; AND I BELIEVE WE WILL BE ABLE TO DETERMINE THAT. AND IN THAT CASE, WE ARE MAKING MEASUREMENTS IN THE RIGHT PLACES TO DO SO; THAT IS, IN THE HIGH-LATITUDE REGIONS WHERE WE EXPECT DISSOLUTION TO OCCUR. AND THAT IS ONE OF THE GOALS OF THE REPEAT . . . PROGRAM TO LOOK AT THAT.
DR. FIELD: CHRIS FIELD, CARNEGIE.

MY QUESTION IS MAINLY FOR DICK, AND IT CONCERNS THE FACT THAT IF DISSOLUTION OF CALCIUM CARBONATE DOES OCCUR, AS I UNDERSTAND, THERE IS ALSO A NET UPTAKE OF CO2 FROM THE ATMOSPHERE.
I WONDER WHAT IS THE CURRENT STATUS OF THINKING ABOUT WHETHER THIS REPRESENTS MECHANISMS THAT MIGHT RESULT IN AN INCREASE IN OCEAN UPTAKE AT SOME POINT THAT WOULD BE AN IMPORTANT FACTOR IN THE OVERALL ATMOSPHERIC CARBON BALANCE.
DR. DONEY: I WILL TAKE THAT ONE, CHRIS.
THE STUDIES THAT HAVE BEEN DONE HAVE EXTRAPOLATED THE KIND OF LABORATORY OR BATHTUB EXPERIMENTS THAT VICKI SUGGESTED. THEY LOOK AT -- THE CURRENT ESTIMATES, IF YOU FOLLOWED AN IPCC TRAJECTORY, YOU GET ABOUT A 50-PERCENT REDUCTION IN THE OPEN OCEAN CALCIFICATION RATE. THOSE WOULD LEAD TO ABOUT -- I THINK IT IS ABOUT A 20-OR-30-PPM DECREASE IN ATMOSPHERIC CO2. THAT'S THE ORDER OF THAT FEEDBACK. SO IT'S THE SIGN YOU WOULD EXPECT. IT'S NOT ENORMOUS, BUT IT'S WITHIN THE RANGE OF SOME OF THE OTHER CLIMATE FEEDBACKS.
THE ONLY CAVEAT I WOULD ADD TO THAT, THOSE ARE BASED ON SORT OF OLD ESTIMATES OF HOW MUCH CALCIFICATION IS ACTUALLY GOING ON IN THE OCEAN; AND SOME OF THE WORK THAT'S BEEN GOING ON, PARTICULARLY

RELATED TO STUDIES OF THE WILLS JADEOFF (PHONETIC) SURVEY LOOKING AT CHANGES IN ALKALINITY IN SPACE, SUGGEST THAT MAYBE CALCIFICATION IS ACTUALLY GOING ON MORE RAPIDLY THAN WE THOUGHT, BUT A LOT OF IT IS BEING REMINERALIZED FAIRLY SHALLOW IN THE WATER COLUMN. SO THERE IS SOME UNCERTAINY IN THAT. IT

MIGHT ACTUALLY INCREASE THOSE NUMBERS. THAT IS SORT OF THE STATE OF THE ART.

MS. DECKER: HI, CYNTHIA DECKER FROM NOAA. THERE'S BEEN A LOT OF WORK DONE RECENTLY ON A LOT OF DEEP-WATER COMMUNITIES, INCLUDING THINGS LIKE BENSON SEEMS (PHONETIC) COMMUNITIES AND COMMUNITIES IN THE ABYSSAL PLAINS AND IN THE DEEP MID WATERS OF THE OCEAN RIDGES.

DO WE HAVE ANY SENSE AT ALL WHAT THE IMPACT OF THIS MIGHT BE ON THOSE COMMUNITIES, EITHER DIRECT OR INDIRECT?

DR. FEELY: THE BEST WORK THAT I KNOW OF IS THE WORK OF JOHN GANOTE (PHONETIC), WHO WORKS AT THE MARINE BIOLOGICAL OBSERVATORY IN SEATTLE; AND WHAT HE HAS SHOWN IN SOME OF THE RECENT PAPERS IS THAT THERE IS SOME CONCERN ABOUT MANY OF THESE ORGANISMS BECAUSE IN A SCENARIO BY THE END OF THIS CENTURY, OVER 70 PERCENT OF THE DEEP-WATER CORALS WOULD BE IN WATERS THAT ARE CORROSIVE TO FORMATION OF CALCIUM

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CARBONATE, AND THERE HAVE BEEN NO STUDIES TO DATE THAT HAVE SHOWN WHAT THE IMPACTS OF THE CORROSIVE WATERS WOULD BE ON THEIR CALCIFICATION. SO WE SIMPLY DO NOT HAVE THE EVIDENCE TO DESCRIBE THEIR IMPACTS. THERE ARE STUDIES BEING DONE IN EUROPE RIGHT NOW WITH SOME CORAL SPECIES THAT IS BEING DONE, FOR EXAMPLE, IN GERMANY AND ALSO IN NORWAY; BUT TO DATE, THERE'S NO PUBLISHED RESULTS FROM THAT YET.

DR. BISHOP: HI, I'M JIM BISHOP; UNIVERSITY OF CALIFORNIA, BERKELEY, AND I'M ALSO AFFILIATED WITH LAWRENCE BERKELEY LAB.

THE POINT SEEMS TO BE ONE OF TRYING TO UNDERSTAND THE DYNAMICS OF THE CARBON CYCLE AND THIS SOFT TISSUE AND HARD TISSUE PUMP THAT DRIVES SEDIMENTATION. AND I'M WONDERING IF, OR I WOULD JUST LIKE TO SAY THAT, IN FACT, THE TECHNOLOGY THAT KEN MELVILLE CALLED FOR IN TERMS OF PUTTING CARBON ON CARGO FLOATS, WE HAVE ALREADY DONE THIS FOR PARTICULAR COMPONENTS, AND WE HAVE DEVELOPED A SYSTEM CAPABLE OF FOLLOWING BOTH ORGANIC AND INORGANIC CARBON SEDIMENTATION.

ONE THING THAT WE KNOW WITH THESE SENSORS IS THAT PARTICLES HAVE VERY SHORT RESIDENCE TIMES IN THE WATER COLUMN AND, THEREFORE, ARE VERY SENSITIVE TO CHANGES IN SUCH THINGS AS CARBONATE SATURATION,

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AND WE WON'T BE ABLE TO GET THE PROCESSED INFORMATION THAT IS REQUIRED TO DO A BETTER JOB OF MODELING PREDICTION.

I'M WONDERING IF, IN FACT, KEN MELVILLE'S CALL FOR A CARBON ARGO MIGHT BE A GOOD THING INVOLVING AUTONOMOUS VEHICLES THAT FOLLOW THESE PROCESSES YEAR-ROUND.

THANKS.

DR. WEISS: THAT'S A LOADED QUESTION. ANYBODY WANT TO TAKE IT?

DR. DONEY: I THINK THAT THERE IS A STRONG

DESIRE WITHIN THE OCEAN BIOGEOCHEMICAL COMMUNITY TO TAKE ADVANTAGE OF AUTONOMOUS VEHICLES, INCLUDING ARGO. THERE WAS A WORKING GROUP PUT TOGETHER A COUPLE OF YEARS AGO TO TRY TO ADVOCATE FOR ADDING OXYGEN SENSORS TO THE ARGO NETWORK, AS OXYGEN IS A SENSITIVE MEASURE OF BOTH CHANGES IN SOLUBILITY AND TEMPERATURE BUT ALSO BIOGEOCHEMICAL CYCLING AND THE SOFT TISSUE PROBLEM.

I THINK IT IS A MATTER OF WHEN THE SENSORS ARE MATURE ENOUGH TO BE PUT ON THE ARRAY AND THEN WHAT'S THE COST. THERE IS ALWAYS A POWER COST AND OTHER COSTS ASSOCIATED WITH ARGO. I'M ALL FOR MOVING INTO AN OXYGEN AND CARBON ARGO. IT'S JUST A MATTER OF WHAT THE RIGHT WAY TO DO THAT IS SO THAT ARGO CAN

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CONTINUE TO DO THE PHYSICAL OBSERVING THAT IT NEEDS TO DO AS PART OF ITS MISSION AND THAT THE BIOGEOCHEMICAL COMMUNITY ADDS TO THAT AND DOESN'T DETRACT FROM IN THE PHYSICAL SIDE.

DR. BISHOP: WELL, I WOULD SAY THE QUESTION FOR THE PHYSICS COMMUNITY IS EXACTLY THAT, ADDING THE BIOGEOCHEMICAL COMPONENT ON TOP OF WHAT THE PHYSICS IS ALREADY PROVIDING. AND YES, OXYGEN IS A GOOD PARAMETER. BUT I WOULD ALSO STRONGLY ADD THAT THERE ARE OTHER ACTUALLY QUITE WELL-PROVEN SENSORS THAT ARE READY TO GO.

THANKS.

DR. WEISS: OKAY. LET'S JOIN IN THANKING THIS SESSION'S SPEAKERS, PLEASE.