Characterization of carbon and nitrogen uptake by marine biota in the Indian Ocean

A THESIS

submitted for the Award of Ph. D. degree of

MOHANLAL SUKHADIA UNIVERSITY

in the

Faculty of Science

by

Arvind Singh

Under the Supervision of

Dr. R. Ramesh, **FNA, FASc, FNASc, FTWAS**
Senior Professor
Geosciences Division
Physical Research Laboratory, Ahmedabad, India.

DEPARTMENT OF PHYSICS

MOHANLAL SUKHADIA UNIVERSITY

UDAIPUR

2011

CERTIFICATE

I feel great pleasure in certifying the thesis entitled "**Characterization of carbon and nitrogen uptake by marine biota in the Indian Ocean**" by Arvind Singh under my guidance. He has completed the following requirements as per Ph.D. regulations of the University

(a) Course work as per the university rules.

(b) Residential requirements of the university.

(c) Presented his work in the departmental committee.

(d) Published/accepted minimum of one research paper in a referred research journal,

I am satisfied with the analysis of data, interpretation of results and conclusions drawn.

I recommend the submission of thesis.

Date: 2011

Prof. R. Ramesh
(Supervisor)
Physical Research Laboratory
Ahmedabad, India.

Countersigned by
Head of the Department

DECLARATION

*I Mr. Arvind Singh, S/o Mr. Bhisham Singh Bhadoriya, resident of Room No. - 203, Thaltej Hostel, PRL residences, Navrangpura, Ahmedabad - 380009, hereby declare that the research work incorporated in the present thesis entitled "***Characterization of carbon and nitrogen uptake by marine biota in the Indian Ocean***" is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required. I solely own the responsibility for the originality of the entire content.*

Date:

Arvind Singh

(Author)

Dedicated To

my family

Acknowledgements

Whatever little I know today, I owe it to my teachers, friends, colleagues and family members rather than reading the printed pages and it is a great pleasure to thank all who supported me with dedicated spirit and have been part of my life at PRL.

First and foremost I offer my sincerest gratitude to my thesis supervisor, Prof. Rengaswamy Ramesh, who has motivated me throughout my thesis period with his patience and knowledge whilst allowing me the room to work in my own way. He made oceanography an easy subject for me with his style of teaching otherwise I would have taken a little longer while changing my subject from Physical Sciences to Ocean Sciences. I must thank him for regularly inviting me to weekend get togethers at his home. Aside from having a fun time, this offered me a unique opportunity to interact with other professors informally and discuss rather freely about research. Prof. Ramesh has been an immense help throughout my time and I have learnt to extract wisdom from his anecdotes, witticism and uniquely own eccentricities! My culinary skills have been boosted too thanks to him ("A chemist must always be a good cook!"). I am deeply indebted to all that he has taught me.

I am grateful to Drs. Marcel M.M. Kuypers and Gaute Lavik, at Max Plank Institute for Marine Microbiology (MPIMM), Bremen, Germany, for teaching me the complexity of nitrogen cycle within a few weeks and motivating for doing research in this field. They offered me the chance to do a significant part of my thesis work at MPIMM. I thank Hang, Yudi, Sergio, Moritz, Hannah, Tim, Abdul, Birgit, Daniela, Gabi, Thomas, Sabine and other members of MPIMM for making my stay memorable at Bremen. It was grateful that Dr. Wajih Naqvi's visit coincided with mine at MPIMM. I thank him for explaining to me many processes that occur in the Arabian Sea. I must thank POGO-SCOR for providing me the fellowship for the project. It was a fantastic experience through which I gained developed my skill set and was exposed to different work ethics in science.

I thank Dr. Anna Godhe for offering me the chance to perform culture experiments, and participate in Mesocosm experiment in future. She has taught me the biological aspect of oceanography. I also thank her daughter Nina and husband Dr. Johan Burman for having making my stay at Mangalore a very comfortable and fun-filled one!

I gratefully acknowledge Prof. M.M. Sarin for his advice, and critical comments during various stages of this thesis work. I am very much indebted to Drs. Sunil Singh, Bhas Bapat, R.P. Singh, R. Rangarajan, Dileep Angom and Prof. J.N. Goswami for teaching the various subjects during course work. I thank Profs. Utpal Sarkar and Anjan Joshipura for their cordial nature and cooperation as Dean

of the institute.

I am specially thankful to Dr. J.S. Ray for his most supporting words and informal scientific discussion during various parties. He stands testament to the fact that a jovial attitude can go a long way!

I thank Dr. M.G. Yadava and R.A. Jani for discussions and helping me in the lab. N. B. Vaghela is thanked for helping me whenever I had any sort of problem in designing any experiment. I thank Drs. Ravi Bhushan, R.D. Deshpande, Vinai Rai, K.K. Marhas, Anil Shukla, D.K. Rao and all the members of Planetary and Geosciences Division for their constructive comments and suggestions during various area seminars and reviews. Their guidance always helped me to improve the quality of the research work.

I am grateful to Dr. M.S. Sheshshayee for providing all the facilities for my sample analyses at University of Agricultural Sciences, Bengaluru.

I am thankful to Profs. Ashok Ambastha and Venkatakrishnan for describing to me the beauty of the Sun. I thank Brajesh, Sanjay, Raja, Shibu ji, Nandita ji, laxmilal ji, Manish, Alkesh, Sanjeev, Ram and their family for making my days memorable at USO.

I am very grateful to all the members of the Computer Center, Library, Purchase, Accounts, Stores and PRL dispensary. My special thanks go to Mrs. Nandini Rao and Mr. Nirav Vaidya for their help during procuring chemicals and instruments for my thesis work. I would also acknowledge people from different sections of PRL: V. Ranganathan, G.P. Patel, N.D. Bhawsar, R.S. Gupta, Parul Parikh, Bankim, Keyur, Senthil, Pradeep, Manan, Sivadasan, Hitendra and others for their help in various stages.

I owe a special appreciation to Profs. B.L. Ahuja and Rajesh Pandey for encouragement during various stages, which has helped me to improve this work. The Physics Department and the Ph.D. section of Mohan Lal Sukhadia University, Udaipur has provided the support I have needed to produce and complete my thesis.

I acknowledge Drs. S. Prasanna Kumar (NIO, Goa), M. Sudhakar, N. Anil Kumar, M. M. Subramaniam, Ravi Mishra (NCAOR, Goa), R.M. Dwivedi, Mini Raman (SAC, Ahmedabad) for giving me the opportunity to participate in various research cruises. Thanks are due to my friends Arvind Sahay and Suhas for making the cruises memorable. I thank the captains, crew and participants in the cruises and Ministry of Earth Sciences for ship time. I also thank ISRO-GBP for funding provided for the cruises.

I spent quality time with my younger friends Anwar, Siddharth, Rahul and Saurabh. I learnt from them in many ways from playing Volleyball to solving puzzles. Kaustubh and Vikas were great company with academics and otherwise. I wish them all a very bright future.

I also benefited from my seniors at PRL who inspired me throughout my thesis work. I thank Subimal, Manish Tiwari, Neeraj Rastogi, Santosh Rai, Morthekai, Antra and Rajesh Kushwaha. Special thanks to Tarun Jha for running the funshow 24 hrs with positive energy. His jokes saw me through a tough day at work!

Collective and individual acknowledgments are also owed to my labmates Amzad, Ashutosh and Rohit. They were always very supportive and always guided me in the right direction. Scientific discussions with them were always very fruitful and enjoyable. My special thanks to Naveen, Shreyas and Satya who have always been an infinite source of encouragement and criticism to my academic career.

During my initial time at PRL, Gyana, Bhavik, Vishal, Anil Ohlan, Anil Tyagi, Praveen, Kallol, Charu, Bindu, Sumita, Waliur, Kirpa, Alok and Sumanta have created lively atmosphere. I thank them all for making my life easy at PRL.

In my daily work, I have been blessed with a friendly and cheerful group. Heartfelt thanks goes out to Ashwini, Vimal, Pankaj, Vineet, Soumya, Bhaswar, Anand, Sandeep, Sreekanth, Ashok, Rohit, Rabiul, Suman, Chauhan, Jayati, Raju, Zulfi, Ketan, Patra, Neeraj, Arvind Saxena, Nita, Digu, and Aditya. All the research scholars of JRF 07-10 batches have been supportive and I wholeheartedly wish them the best.

Words fail in expressing love, strength and inspiration of my family for me. My little niece Anjali who asks me every time I talk with her "*Mamu, aap kab tak padai karte rahoge* (How long will you be studying)?" This question makes me think deeply if I am doing something worthwhile. The question is still left unanswered but at least I came out alive with a doctoral thesis!

Abstract

Primary productivity is mostly limited by the unavailability of reactive nitrogen in the sunlit surface layer of tropical oceans. The supply of such new nitrogen to the surface ocean is through upwelling, N_2 fixation by diazotrophs, riverine flux and atmospheric deposition. The relative and absolute importance of these processes in the Indian Ocean is studied here.

N_2 fixation is estimated directly for the first time using the $^{15}N_2$ tracer technique in the Arabian Sea during the spring inter-monsoon 2009. Estimates are double the values reported earlier and can account for a substantial fraction of the nitrogen gained by the Arabian Sea. Carbon uptake rates are also estimated using the ^{13}C tracer technique. Further, contribution of atmospheric deposition and riverine fluxes to new productivity in the two biogeochemically different basins of the northern Indian Ocean, the Arabian Sea and the Bay of Bengal, is presented. A upper bound of the contribution of atmospheric deposition to new productivity in the northern Indian Ocean is $\sim$2.5%. On an average 1.73 Tg N y^{-1} is deposited into the northern Indian Ocean through dry and wet depostion of aerosols. On the other hand, most of the dissolved inorganic nitrogen ($\sim$81% in the case of the Arabian Sea and 96% in the case of the Bay of Bengal) through riverine flux is not transported to the ocean and is consumed on the course of the rivers or in the estuaries. Coastal Bay of Bengal and Arabian Sea receive $\sim$0.38 Tg N y^{-1} and $\sim$0.06 Tg N y^{-1}, respectively, through rivers. A large variation in the contribution of DIN through river fluxes to new productivity is found in both these basins. Our estimate of nitrogen fluxes through N_2 fixation, aerosols and rivers is a step towards significantly reducing the uncertainty in the global nitrogen budget.

Application of stable isotopes is extended further by simulating nitrogen loss process in the Arabian Sea. An equation describing isotopic fractionation in open systems, wherefrom material is not only removed with isotopic fractionation, but fresh material of a different isotopic composition is added from an external source, is derived. This model is further applied to understand other oceanographic processes as well. With the help of a new data set, spatiotemporal variation in the

oxygen isotopic composition and salinity (δ^{18}O-S) relation of the northern Indian Ocean is studied. While the results are consistent with positive P-E (excess of precipitation over evaporation) over the Bay of Bengal and negative P-E over the eastern Arabian Sea, a significant spatiotemporal variability in the slope (also intercept) of the relation is observed in the Bay; the temporal variability is difficult to discern in the Arabian Sea. Both the slope and intercept appear to be sensitive to rainfall; the slope (intercept) is higher (lower) during years of stronger monsoon. The observed variability in the δ^{18}O-S relation implies that caution needs to be exercised in paleosalinity estimations, especially from the Bay of Bengal, based on δ^{18}O of marine organisms.

Key words: Marine Carbon Cycle, Marine Nitrogen Cycle, Nitrogen fixation, The northern Indian Ocean, Rayleigh fractionation, Aerosol deposition, Riverine flux

Abbreviations

α	fractionation factor between product and source
ϵ	enrichment factor i.e. (α-1)$\times$ 10^3
δ^{18}O	Oxygen isotope composition of water with VSMOW as standard
δ^{15}N	Nitrogen isotope composition of PON with air as standard
‰	per mil (or parts per thousand)
Anammox	Anaerobic Ammonium Oxidation
DIC	Dissolved Inorganic Carbon
DIN	Dissolved Inorganic Nitrogen
DNRA	Dissimilatory Nitrate Reduction to Ammonium
EA	Elemental Analyzer
EP	Export productivity
FIM	Fall Inter monsoon
FORV	Fishery and Oceanographic Research Vessel
GC	Gas Chromatograph
GNIP	Global Network on Isotopes in Precipitation
HNLC	High-nutrient, low-chlorophyll
IAEA	International Atomic Energy Agency
IAPSO	International Association for the Physical Sciences of the Ocean standard seawater
IPCC	Intergovernmental Panel on Climate Change
IRMS	Isotope Ratio Mass Spectrometer
IRS-P4-OCM	Ocean Colour Monitor on Indian Remote Sensing Satellite IRS-P4
ISRO-GBP	Indian Space Research Organisation - Geosphere Biosphere Programme
ITCZ	Inter Tropical Convergence Zone
JGOFS	Joint Global Ocean Flux Study
JRF	Junior Research Fellow
MLD	Mixed Layer Depth

N_r	Reactive Nitrogen
N/P	Nitrate to Phosphate ratio
N/Si	Nitrate to Silicate ratio
NARM	Narmada
NCAOR	National Centre for Antarctic and Ocean Research
ND	no data available
NIO	National Institute Of Oceanography
NOAA-AVHRR	National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer
NP	New Productivity
OMZ	Oxygen Minimum Zone
ORV	Oceanographic Research Vessel
PAR	Photosynthetically Active Radiation
POC	Particulate Organic Carbon
POGO	Partnership for Observation of the Global Oceans
PON	Particulate Organic Nitrogen
PP	Primary Productivity
ppmv	parts per million volume
PRL	Physical Research Laboratory
R	Ratio of heavier to lighter isotopes
S	Salinity
SAC	Space Applications Centre
SCOR	Scientific Committee on Oceanic Research
SIM	Spring Inter monsoon
SM	Summer monsoon
SOM	Soil Organic Matter
SST	Sea Surface Temperature
TAD	Total (wet + dry) atmospheric nitrogen deposition

TRMM	Tropical Rainfall Measuring Mission
UNESCO	United Nations Educational, Scientific and Cultural Organization
VSMOW	Vienna Standard Mean Oceanic Water
WM	Winter monsoon
WMO	World Meteorological Organization

Contents

List of Figures

List of Tables