Study of the Impact of Climate Change on the Biological Productivity of the Arabian Sea using Remote Sensing Approach

SYNOPSIS OF THE THESIS

For the degree of

DOCTOR OF PHILOSOPHY IN BOTANY

Submitted to

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

By

Neha Nandkeolyar

(Registration No. 004)

Guided by

Prof. (Dr.) Garge Sandhya Kiran

Department of Botany
Faculty of Science
The Maharaja Sayajirao University of Baroda
Vadodara – 390 002, Gujarat, India

July 2016

Introduction

In today's era, one of the greatest challenges being faced by human is 'global warming'. There has been a 0.74^{0}C increase in global temperature in last century with more than half of this warming (about 0.4°C) recorded since 1979 and it is projected to increase by 1.8 to 4^{0}C in the 21st century (IPCC AR4, 2007), posing a serious threat to the socio-economic sector worldwide. With oceans covering approximately 70% of the earth's surface, any discussion on climate change would remain incomplete without including the role of the oceans.

The oceans being a fundamental part of the biosphere play an integral role in controlling the regional and the global climate. The rate of the global warming is significantly influenced by the amount of heat and CO_2 absorbed by the oceans. However, the oceans themselves are also being affected by the changing climatic conditions. Time series observation of oceanographic parameters and processes form a crucial method for understanding the oceanic variability and the impact of changing climate on its biological productivity.

The oceanic environment is known to support vast populations of living organisms, which distributed either in to pelagic or in to benthic realm. Phytoplankton and zooplankton together constitute this community and form the primary food source for most of the marine organisms. Phytoplanktons are tiny plant which looks like a cellular organism that gradually turns sunlight into food. The spatial and temporal pattern of phytoplankton affects the abundance and diversity of oceanic marine organisms in particular the fishes and hence the productivity.

The interactions between biological and physical processes of oceanic ecosystem are essence to oceanographic studies (Tang et. al, 2002). The occurrence of phytoplankton, their growth and rate of primary production are influenced as well as regulated by a complex network of the physical factors viz. Sea Surface Temperature (SST), wind, Photosynthetically Active Radiation (PAR) and many others. Therefore, understanding the variability of these physical factors is essential for explaining the spatial-temporal variability of phytoplankton and their biomass. Unfortunately, the vast expanse of the oceans limits its accessibility. However, the availability of satellite data of the ocean surface in recent years has helped immensely in the study of the oceans and its dynamic processes. Ocean color remote sensing is the only means by which regular, synoptic estimates of phytoplankton biomass, indexed as chlorophyll-a concentration can be obtained over much of the world ocean. The chlorophyll is the most essential derived product through remotely sensed water leaving radiances and forms the basis of primary productivity. Remote sensing observations have facilitated monitoring land, ocean and atmospheric parameters and also to predict models for the climate change research. Ocean colour remote sensing provides an important tool to understand the marine processes, ecology and the environmental changes.

One of the important information needed in the context of climate change is the quantification of the trends in the phytoplankton biomass, primary productivity in response to the global environmental changes (Behrenfeld et al, 2005). SST is one of the key oceanographic parameters, exerting an influential role in many of the meteorological and oceanographic physical and biological processes. The IPCC assessment report (Houghton et. al., 1996), declared SST to be on the priority list for climate change research. The adverse impact of rising SST on cyclones (Kumar et al. 2009; Emanuel, 2005; Webster et al., 2005), glaciers (Oerlemans, 1994), sea surface height (Church, 2001; Meehl et al., 2005) and rainfall (Goswami et al., 2006; Zhang et al., 2007), has been well reported. The increase in temperature changes the mixing and stratification of the ocean (Sarmiento et al., 2004) that can have a cascading effect on other oceanographic processes. For a tropical country like India where dependency on monsoon is high, any alteration in its seasonal cycle is detrimental. It has been well investigated that the temperature of the Indian Ocean regulates the genesis and variability of the monsoonal wind (Shukla 1977, Rao and Goswami 1988, Godfrey et al., 1995, Webster et al., 1998, Li et al. 2001). Hence, the role of SST assumes greater significance in Indian context. Even the biological implications of rising SST are disturbing. For instance, variation in the threshold temperature can cause drastic changes in the marine flora, (Tom Schils and Simon C. Wilson 2006) reduce the diversity of macro algae, result in coral bleaching etc.

Indian Ocean is the world's third largest ocean and makes up about 20 percent of the water on earth's surface and the Arabian Sea is a regional sea of the Western Indian Ocean. Being land locked from three sides, it experiences unique circulation pattern, climate and biogeochemical processes (Naqvi et al., 2003). It has been reported to be one of the most productive oceanic zones (Ryther et al., 1966) and the occurrence of phytoplankton blooms has been a constant phenomenon over a major region of the northern Arabian Sea. Numerous investigations in the past have been carried out to analyze the biological productivity of the Arabian Sea. Both in situ and satellite studies, in this regard have been reported. However, a major drawback with respect to in situ observation lies in scarcity of data for climatological studies.

In the present study, the interannual and intra annual variability of the physical factors like SST, u and v components of wind speed and wind stress along with phytoplankton biomass indexed from chlorophyll-a were analysed from different satellite data. Besides, SST, the frequency of cyclones and El Nino and La Nina events in the Arabian Sea, as indicators of Climate Change were also analysed. For an assessment of the biological productivity of the Arabian Sea, chlorophyll –a, the major photosynthetic pigment in the phytoplankton, along with SST, euphotic depth and Photosynthetically Active Radiation (PAR) were used to quantify the primary productivity using Vertically Generalized Productivity Model (VGPM) given by Behrenfeld and Falkowski (1997) was used in which the optimal rate of carbon fixation within a water column was derived from SST.

Study Area

The study area was Arabian Sea with its Gulfs and marginal sea. Being land locked from three sides it experiences unique circulation pattern. The Arabian Sea has two important branches- the Gulf of Aden in the southwest, connecting Arabian Sea with the Red Sea; and the Gulf of Oman to the northwest, connecting Arabian Sea with the Persian Gulf. There are also the gulfs of Khambat and Kutch on the Indian coast. Arabian Sea is located in the northwestern part of the Indian Ocean, between the Arabian Peninsula and the Indian subcontinent. It spans a total area of 1,491,000 square miles. The depth of the sea varies as it joins the Indian Ocean to the south, but it is generally approximated at 8,970 feet. In spite of being a continuous water body, there is a distinct domain specific organized pattern in the Arabian Sea, which needs to be identified, to study the climatological spatial and temporal variability of different physical oceanographic parameters that affect phytoplankton biomass and in turn also affect the biological productivity. Each sub-region has its own originality in terms of current patterns, physical characteristics, physiochemical qualities, dominant species and biodiversity.

Objectives

The present study was carried out with the following objectives

a) Is the climate of Arabian Sea changing?
    - Evidence from multi decadal study of SST
    - Evidences from wind speed and wind stress
    - Evidences from Frequency of Cyclonic events
    - Evidences from El Nino, La Nina and ENSO effects

b) Multi decadal study of spatial and temporal variability of phytoplankton biomass in the Arabian Sea

c) Changing pattern of the Biological Productivity of Arabian Sea and its correlation with the climatic variability of SST and wind speed

Data Used

For the present work multi temporal high resolution satellite data sets that give better results than in situ data in terms of its continuity and its spatial coverage were used. In this study the long term spatial and temporal variations of SST in different regions of the Arabian Sea using was analyzed using monthly SST data NOAA AVHRR Pathfinder (version 5.0) of 4 km resolution was obtained from NASA'S Jet Propulsion Laboratory's Physical oceanographic centre (http://podaac.jpl.nasa.gov/) for the period 1985-2009. SST field was derived through the

MCSST algorithm. Besides to study long term trend of SST, monthly Extended Reconstructed SST (ersst) data from NCEP for the period 1950 to 2015 was used.

For wind speed and wind stress, the monthly (level 3.5) gridded cross calibrated multiplatform (CCMP) ocean surface wind speed at 25 km spatial resolution derived through cross calibration and assimilation of data from SSM/I, TMI, AMSRE, SeaWinds on QuikSCAT, and SeaWinds on ADEOSII, for the period from 1987 to 2010 was used for analysis.

For Chlorophyll-*a,* the monthly data from CZCS, SeaWifs and MODIS sensors for the period 1978 to 1986, 1997 to 2010 and 2002 to 2015, respectively were accessed from http://oceandata.sci.gsfc.nasa.gov.

Methodology

For the purpose of detailed examination of the climatological trend of SST and wind to study the impact of climate change on the biological productivity, the entire Arabian Sea basin was subdivided into the following subsets:

a) Western Indian Ocean Basin (32^0E-80^0E; 32^0N -10^0S)
b) Arabian Sea with Gulf (32^0E-78^0E; 30^0N- 0^0N)
c) Arabian Sea excluding the Gulf (50^0E-78^0E; 25^0N-0^0N)
d) Southern Arabian Sea (32^0E-78^0E; 15^0N -0^0N)
e) Northern Arabian Sea (32^0E-78^0E; 30^0N-15^0N)
f) Northern Arabian Sea (Bloom Area) (60^0E-69^0E; 25^0N-15^0N)
g) North Eastern Arabian Sea (64^0E-78^0E; 30^0N-15^0S)
h) North Western Arabian Sea (32^0E-64^0E; 30^0N -15^0S)
i) Eastern Arabian Sea (64^0E-78^0E; 30^0N-0^0S)
j) Western Arabian sea (40^0E-64^0E; 30^0N-0^0S)
k) South Eastern Arabian Sea (64^0E-78^0E; 15^0N-0^0S)
l) South Western Arabian Sea (40^0E-64^0E; 15^0N-0^0S)
m) 0-10^0 South
n) Persian Gulf
o) Gulf of Oman
p) Red Sea
q) Gulf of Aden
r) Gulf of Kuchchh
s) Gulf of Khambat

For each of the defined areas of the Arabian Sea, the monthly SST and Chlorophyll -a images were masked to avoid the land and clouds using image-processing software (ENVI 4.1 and ERDAS 9.0). For chlorophyll-a images, the chlorophyll-a concentration from waters shallower than 50 meters depth were masked using the bathymetric image generated using SEADAS 7.0

software, to exclude the erroneous estimates of chlorophyll-a concentration resulting from the bio-optically complex case-2 waters. For wind speed and wind stress analysis, the monthly data was analyzed using excel for netcdf files, Surfer and ERDAS 9.0 software.

For the estimation of Primary Productivity of the Arabian Sea, the widely used Vertically Generalized Production Model (VGPM) model given by Behrenfeld and Falkowski (1997) was used in which the optimal rate of carbon fixation within a water column was derived from SST.

The monthly, seasonal and annual climatological means were calculated. The inter annual variability for each month was analyzed using the monthly anomalies computed by subtracting the climatological mean from the monthly mean, which was then normalized to the standard deviation for that month. Trend analysis was carried out using the nonparametric Mann-Kendall (MK) test and regression analysis.

Results

Warming of the Arabian Sea

To study the impact of climate change on the biological productivity of Arabian Sea, the long term climatic variability of the key oceanographic feature –SST was analysed from 1950 to 2015. It was found that in the last 65 years, the SST of Arabian Sea has increased by 1.29^{0}C across the years. Inter decadal study revealed that the average temperature of Arabian Sea had increased gradually from 1950s to 1990s and thereafter there was a sharp rise in SST from 2000s to 2010s. However, in the last 5 years from 2011 to 2015, there has been the maximum rise in SST as compared to any of the previous decades.

The increase in SST was found for all the months from January to December in the range of 0.69 to 1.7^{0}C. Seasonal variation in rising SST was also observed with highest increase in SST during the autumn inter monsoon (October, November) by an average of 1.65^{0}C. The two of the biologically productive seasons i.e. the south west monsoon season and the north east monsoon season also showed significant rise in temperature in the range of 1.15^{0}C to 1.46^{0}C, in the last 65 years, which is posing dangers for the phytoplankton community structure and the primary productivity rates as well.

Distinct zonal pattern was seen in terms of SST variation in the Arabian Sea with north eastern and north western 0.79^{0}C and 24^{0}C cooler than the Arabian Sea basin. For all the 19 domains studied within the Arabian Sea, the peak SST was found to be in the month of May while the minimum SST was found to be in the month of July. Amongst the 19 domains, the highest rise in SST was observed in the Gulfs of Arabian Sea, especially Gulf of Oman and Persian Gulf, where maximum coastal development work are bring carried out and their impact on rising SST is well observed.

Effect of El Niño and La Niña on SST of Arabian Sea

In the present study to study the climatic effects of El Niño and La Niña on rising SST of Arabian Sea, a comparative analysis of the normalized SST anomaly for Arabian Sea and ENSO (El Niño- Southern Oscillation) using the Multivariate ENSO Index (MEI) provided by the Climate Diagnostic Centre (http://www.cdc.noaa.gov), was also carried out. MEI based upon both atmospheric and oceanic parameters and it denotes the coupled nature of the ENSO phenomena. The influence of the ENSO on SST of Arabian Sea was clearly observed. However, not all the El Niño or La Niña had similar impact. For example the El Niño of 1991-1992 did not influence the waters of the Arabian Sea like the one of 1997-1998 where the anomaly reached up to +3.0. However, the normalized SST anomaly increased drastically from 1991-1995 (extended El Nino) from -3.0 to +1.0. Correlation of SST anomalies for different domains of the Arabian Sea with MEI, was also carried out in the present work. February, May, June, July and November were the month where the rising SST for almost all the domains of Arabian Sea showed positive correlation (~ +0.64) with MEI.

Changing trend of wind speed over Arabian Sea

One of the other crucial oceanographic features affecting the nutrient supply for the phytoplankton in the ocean is wind. In the present study wind speed and wind stress derived from the scatterometer data was analysed for the period 1987 to 2011. The wind speed, in contrast to the SST was found to be of decreasing trend from for the Arabian Sea basin. It was observed that in the Arabian Sea, there has been a gradual decrease in the speed of the u as well as v component of the wind speed across all the months of the year. The wind speed for the Western Indian Ocean decreased by 0.32 m/sec, and the rate of decrease was 0.023m/sec. per year. Inter-annual variability pattern of wind speed for Arabian Sea was found to be similar to the Western Indian Ocean. However the magnitude of change was different in the western and the eastern domains of the Arabian Sea Basin. In the Arabian Sea Basin, from 1999 to 2009 the normalized wind anomaly index decreased by 1.95 with annual decrease of 0.165, while in the north western parts the decrease was 0.26 with annual decrease of 0.018. The year 2000 and 2009 showed deviation of more than 1.8 (+/-) from the climatological mean of the Arabian Sea. In the north eastern domainin the Overall from 1987 to 2011, a significant decrease in wind speed was observed in the Arabian Sea basin, which could be a reason for less nutrient mixing and probably leading to less productivity.

Phytoplankton biomass and productivity of Arabian Sea

To study the changing pattern of primary productivity and it correlation with the climatological parameters like SST and wind speed, phytoplankton biomass indexed from chlorophyll-a concentration in the Arabian Sea was studied from 1987 to 2015 using multi temporal satellite data of the sensors CZCS, SeaWifs and MODIS. It was observed that across the years the chlorophyll-variability has decreased significantly in all the domains of the Arabian Sea. The chlorophyll-a concentration and hence phytoplankton biomass was found to be highest in the north western domain of the Arabian Sea. While the basin scale average chlorophyll-a was found to be 0.44 mg/m^3, in the north western part, it was 1.14 mg/m^3. The intra annual variability also showed difference in the north eastern and north western domains. In the Western Indian Ocean and Arabian Sea Basin, the maximum chlorophyll- a concentration was found in the month of September, while in the north western domain, August (average chlorophyll-a conc. of 2.0 mg/m^3) showed the peak instead of September (average chlorophyll-a conc. of 1.8 mg/m^3). For the north eastern domain it was found that instead of the south-west monsoon season, the maximum chlorophyll-a concentration as found during the north-east monsoon season (February). However, the multi decadal study of chlorophyll-a, widely used as an index of phytoplankton biomass clearly showed a decreasing trend across the decades from 1978 to 2010. The interannual variability was clearly observed along with the effects of ENSO and El Nino years during which the phytoplankton biomass was comparatively very low. The productivity pattern estimated using VGPM model also depicted a declining trend in the entire basin of Arabian Sea. Seasonal variation was observed with maximum productivity during the south west monsoon period and the minimum during summer season. The changing pattern and trend of SST, wind speed and chlorophyll-a concentration correlated with the decreasing productivity across the years.

Conclusion

Analysis of phytoplankton biomass, the primary producers in the marine ecosystem is required to study the effect of climate change. Arabian Sea being an important productive oceanic region exhibit seasonal phytoplankton blooms. These blooms exhibit changing pattern in terms of their biomass and productivity which correlated highly with the climatological factors like SST and wind speed. This fact was distinctly brought out from the present study. The study carried out over 19 different domains of Arabian Sea highlighted a distinct change in temperature and wind speed - the abiotic components. A significant warming trend was seen in the entire Arabian Sea basin. From 1950 to 2015, the rise in temperature ranged from 0.22^0C to 0.48^0C/decade where as from 1987 to 2011 wind speed decreased in the range of 0.5 to 1.35 m/s. The biomass analysis over the same domains exhibited a significant decline suggesting the impact of climatic factors like SST and wind speed. Thus the understanding of the changing productivity of phytoplankton biomass which from the basic trophic structure of an aquatic ecosystem is the need of the hour as it can destroy any other link in the food web changing the entire ecosystem balance.

References

1. Ryther, J.H., Hall, J.R., Pease, A.K., Bakun, A., Jones, M.M., (1966). Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnology and Oceanography* 11, 371–380.

2. Dwivedi, R.M., Raman, M., Parab, S., Matondkar, S.G.P. and Nayak, S., (2006). Influence of the Northeasterly trade winds on intensity of winter bloom in the Northern Arabian Sea. *Current Science*, 90, 1397-1406.

3. S.W. A. Naqvi, J. W. Moffett, M. U. Gauns, P. V. Narvekar, A. K. Pratihary, H. Naik, D. M. Shenoy,D. A. Jayakumar, T. J. Goepfert, P. K. Patra, A. Al-Azri, and S. I. Ahmed, (2010). The Arabian Sea as a high-nutrient, low-chlorophyll region during the late Southwest Monsoon. *Biogeosciences,* 7, 2091–2100.

4. Gregg W. W., Conkright, M. E., Ginoux, P., O'Reilly, J.E., and Casey, N. W, (2003). Ocean primary production and climate: Global decadal changes, *Geophysical Research Letter*, 30, 1809.

5. Goes, J. I., Thoppil, P. G., Gomes, H. R., and Fasullo, J. T., (2005). Warming of the Eurasian landmass is making the Arabian Sea more productive. *Science*, 308, 545–547.

6. Prakash, S. and Ramesh, R. Is the Arabian Sea getting more productive? (2007). *Current. Science*. 92, 667–671.

7. Naqvi, S. W. A., Naik, H., and Narvekar, P. V., (2003). The Arabian Sea, in: Biogeochemistry of Marine Systems, edited by: Black, K. and Shimmield, G., Blackwell, Oxford, 156–206.

8. S. Prasanna Kumar, Raj P. Roshin, Jayu Narvekar, P.K. Dinesh Kumar, E. Vivekanandan, (2009). Response of the Arabian Sea to global warming and associated regional climate shift. *Marine Environmental Research,* 68, 217–222.

9. Tang, D., H. Kawamura and A. Luis (2002). Short-term variability of phytoplankton blooms associated with a cold eddy in the northwestern Arabian Sea. *Remote Sensing of Environment*, 81, 81-89.

10. Chaturvedi Neera (2005). Variability of Chlorophyll concentration in the Arabian Sea and Bay of Bengal as observed from SeaWiFS data from 1997-2000 and its interrelationship with Sea Surface Temperature (SST) derived from NOAA AVHRR. *International Journal of Remote Sensing*, 26(17), 3695-3706.

11. Watson, A.J., Robinson, C., Robertson, J.E., Williams, P.J. Le B. and Fasham, M.J.R., (1991).Spatial variability in the sink for atmospheric carbon dioxide in the North Atlantic. *Nature,* 350, 50-53.

12. Hays, G.C., Richardson, A.J. and Robinson, C., (2005).Climate change and marine plankton. *Trends in Ecology and Evolution*, 20 (6), 337-344.

13. Harnstrom, K., I. Karunsagar and A. Godhe (2008). Phytoplankton species assemblages and their relationship to hydrographic factors - a study at the old port in Mangalore in coastal Arabian Sea. *Indian Journal of Marine Science,* 28(2), 224-234.

14. Prasanna Kumar, S., P.M. Muraleedharan., T.G. Prasad., M. Gauns., N. Ramaiah., S.N. de'Souza., S. Sardesai and M. Madhupratap (2002).Why is the Bay of Bengal less productive during summer monsoon compared to Arabian Sea? *Geophysical Research Letters*, 29(24), 88.1-88.4.

15. Chaturvedi, N., Shah, M., Ajai and Y T Jasrai (2013). Is there impact of climate change on biological productivity in the Indian Ocean? *Indian Journal of Geo Marine Science*, 42 (1), 50-57.

16. Chaturvedi Neera (2003). Application of Remote Sensing to biological Oceanography: Indian Context. *Recent Advances in Environmental Science*, 349-366.

17. Michel J Behrenfeld, Emmanuel Boss, David A. Siegel, and Donald M Shea (2005). Carbon-based ocean productivity and phytoplankton physiology from space. *Global Biogeochemical Cycles*, 19, GB1006, doi: 10.1029/2004GB002299.

18. Polovina J, Howell E and M Abecassis (2008). Ocean's least productive waters are expanding. *Geophysical Research Letters*, Vol.35, L03618, doi: 10.1029/2007GL031745.

19. Chaturvedi, N., and A. Narain (2003). Chlorophyll distribution pattern in the Arabian Sea: seasonal and regional variability, as observed from SeaWiFS data. *International Journal of Remote Sensing*, 24, 511- 518, doi: 10.1080/01431160304988.

20. O'Reilly, J. E., Maritorena, Mitchel, B. G., Seigal, D. A., Carder, K. L., Garver, S. A., Kahru, M. and C R Mc Clain (1998). Ocean Color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research*, 103, 24937-24953.

21. Madhupratap, M., S. Prasanna Kumar.,P.M. A. Bhattathiri., M. Dileep Kumar., S.Raghukumar., K.K.C. Nair and N. Ramaiah (1996). Mechanism of the biological response to winter cooling in the northeastern Arabian Sea. *Nature*, 384, 549-552.

22. Dey, S. and S.P. Singh (2003). Comparison of chlorophyll distributions in the northeastern Arabian Sea and southern Bay of Bengal using IRS-P4 Ocean Color Monitor data. *Remote Sensing of Environment,* 85,424–428.

23. Banse, K. & McClain, C.R. (1986). Winter blooms of phytoplankton in the Arabian Sea as observed by the Coastal Zone Colour Scanner. *Marine Ecology Progress Series,* 34: 201-211.

24. Banse, K., Vijayaraghavan, S. & Madhupratap, M. (1996). On the possible causes of the seasonal phytoplankton blooms along the southwest coast of India. *Indian Journal of Marine Science,* 25: 283-289.

25. Devassy, V.P., Bhattathiri, P.M.A. & Qasim, S.Z. (1978). Trichodesmium phenomenon. *Indian Journal of Marine Science,*7: 168-186.

26. Subramaniam, A., Brown, C.W., Hood, R.R., Carpenter, E.J. & Capone D.G. (2002). Detecting Trichodesmium blooms in SeaWiFS imagery. *Deep Sea Research, II*, (49):107-121.

27. Sarangi R.K., Chauhan P. & Nayak S. (2001).Phytoplankton bloom monitoring in the offshore water of Northern Arabian Sea using IRS-P4 OCM Satellite data. *Indian Journal of Marine Science*, 30 (4):214-221.

28. Levitus, S., J. Antonov, *et al*. (2005).Warming of the world ocean. *Geophysical Research Letters* 32(1).

29. Platt,T.and Sathyendranath,S.(1988).Oceanic primary production: Estimation by remote sensing at local and regional scales.*Science*,241:1613-1620.

30. Sathyendranath, S., Gouveia, A. D., Shetye, S. R., Ravindran, P. and Platt,T. (1991).Biological control of surface temperature in the Arabian Sea. *Nature*, 349:54-56.

31. Topliss, B. J. and Platt,T.(1986). Passive fluorescence and photosynthesis in the ocean: implications for remote sensing. *Deep Sea Research* I, 33:849-864.

(Neha Nandkeolyar)
Ph.D. Student

Prof. (Dr.) Garge Sandhya Kiran
Guide & Head
Dept. of Botany, Faculty of Science

Dean
Faculty of Science