NCBS Review Board Committee Members – January 2020

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To summarise our overall findings, we feel that NCBS has developed into an internationally renowned and competitive research centre in broad areas of the life sciences, whose excellence reflects the wisdom of TIFR in creating and nourishing this aspect of its broad portfolio. NCBS has created considerable value for the TIFR system, not only through its intramural research but also through its role in creating new institutes - both within and outside of the TIFR system, in Bengaluru and elsewhere in India. NCBS is open in the best sense, collaborating widely, organising both user facilities and diverse training opportunities for scientists across India and taking an important role in national initiatives in which the life sciences and life science research are a major part. NCBS can be considered a national "treasure" of which everyone at TIFR, indeed throughout India should be proud.

Our report consists of an initial summary of the main points of importance for the TIFR Council in "bullet" format. We then expand on various sections in more detail. Although we do not include them in this report (so as not to dilute the focus on NCBS as a whole as part of TIFR), we have sent evaluations of the activities of the individual Principal Investigators to NCBS management, largely focussing on their research but also noting where their efforts have provided the basis for other sections of this report that impact broader areas of NCBS activity. We found the quality of the individual faculty members to be very impressive.

Brief Summary of important issues

- The NCBS system of hiring young investigators and granting them independence has generated a cohort of outstanding researchers, largely by repatriation from the US and Europe, who have significantly contributed to raising the international visibility of Indian Research in the Life Sciences. Faculty members have left NCBS to take up top leadership posts, e.g. the Directorships of IISER and inSTEM, and the many trained PhD and postdoctoral fellows have enriched Indian academia and industry as well as leaving for further training abroad. For a relatively small institute, NCBS has had a very large impact. It has started original and very impactful programmes like the ecology and diversity and chemical ecology programmes, which are internationally unique and of great value. IndiaBioscience is a networking and information transfer system for all Indian life scientists; it provides them with a forum to discuss common challenges, common interests and a host of other topics. This was created by NCBS and is still managed from there. From outside India, NCBS is generally seen as a prime quality, internationally competitive, research institute in the life sciences.
- In the context of Bangalore, NCBS has spearheaded the development of inSTEM, now an independent institute that operates in stem cell research and regenerative medicine and C-CAM, a combination of an innovation arm, helping to capitalise on IP generated in the life sciences, an incubator facility for start-up biotech companies and an operator of Core Facilities. They are organised together with NCBS and inSTEM and then made available to the entire national research community. These are very valuable initiatives, and another of many examples of how the structure of NCBS, based on PIs doing fundamental research, has broad impact on creating a healthy research and innovation ecosystem. The three institutes collectively form the

Bangalore Life Sciences Cluster which is a very productive local ecosystem in which NCBS can continue to flourish and improve, making translational links to both biotechnology and medical research.

- The Bangalore Sustainability Forum was another initiative of NCBS that has now added other partners to explore issues like Urban water systems, Urban diversity and the effects of climate change on Urban areas from both a scientific and societal perspective. It is an excellent example of community engagement.
- NCBS has incubated, and still houses, the early phase of the Science Gallery of Karnataka, a state science outreach initiative which is now in the process of constructing a dedicated building in central Bangalore
- In the context of TIFR, NCBS has helped set up ICTS in Bangalore as a separate TIFR centre, and NCBS faculty are still involved in hiring and teaching there. Several faculty members are also actively engaged in recruitment, teaching, or as a Member of the Management Board in the early phase of TIFR Hyderabad development. It seems to us very important for TIFR to utilise the advice and expertise of NCBS as much as possible in planning the life science division in Hyderabad, to ensure that the two centres are complementary and carry out activities in a coordinated way from the beginning.
- NCBS researchers also collaborate with researchers in other parts of TIFR including in Hyderabad, ICTS and Mumbai. From our brief consultations with roughly half of the NCBS faculty, we identified 20 joint research projects that are provided in Annex 1. Some funding dedicated to promote cross-institute collaborations in TIFR would be valuable in sustaining and increasing this number further.
- NCBS has an excellent programme of courses, conferences and workshops for external researchers with many events each year (30 per year on average over the five-year period) organised by NCBS faculty and core facility managers. This is a tremendous service to the scientific community nationally.
- NCBS has the capacity to contribute to and lead national initiatives, including in the areas of Biodiversity, Brain Science/Neurological Disease and Computational and Theoretical Biology. We provide a more detailed description of these three areas below. In the context of the DAE, an example area to which NCBS is in a position to contribute is crop improvement. We encourage NCBS to engage in developing initiatives in these areas, all of which will require both new recruitment and sustainable funding mechanisms, as well as a critical dependence on continued funding of the bedrock of high-quality research groups in diverse areas of the life sciences. In addition, thought has to be given to ways, including e.g. joint appointments, by which the tenure of faculty critical to these initiatives can be extended beyond the current, very early, mandatory retirement age.
- NCBS is entering a phase of turnover and moderate growth with roughly 3 recruitments per year in the next 5 years predicted. We recommend that some of these recruits (perhaps 50%) be planned strategically to strengthen areas in which NCBS is engaging in national initiatives. These areas are identified in the more detailed descriptions below.
- One urgent aspect of turnover is that both the Director and the Dean of NCBS, in other words the senior scientific leadership, are scheduled to turn over in roughly three years. As we discuss in more detail below, we are of the opinion that the enforced retirement age of 60 at TIFR, being at a significantly younger age than in the rest of

the world, is damaging to the institute. It is critical to consider this issue in relation to the upcoming leadership turnover and to urgently put together either a succession plan or a retention plan for the leadership currently in place.

- NCBS fares extremely well in obtaining competitive funding from national and, particularly, international sources, with a total volume of over 37 Crores in the last year of reporting and 162 Crores over the five-year period of the report. We commend NCBS researchers on this success with research funding agencies and encourage the organisation to continue to develop a programme for more general funding sources such as foundations, individual donors and industry.
- NCBS is an extremely attractive place for PhD students, many of whom do very well and are able to go on to first-rate academic and non-academic careers nationally and internationally. Roughly 50% each either stay in India or go abroad, 75% of them staying in academia. 16% of NCBS alumni are now in Faculty positions in India and 11% in faculty positions abroad while 15% enter industry and almost 10% pursue other science-related careers.
- TIFR has made outstanding contributions, but It will change considerably in the next decade, given the scale of the plans for the Hyderabad centre. Even at its present size, the administrative organisation between TIFR and its centres, or at least NCBS, is far from optimal. We were provided with several examples of delays, often considerable delays (details can be obtained from NCBS management if necessary), in hiring and procurement caused by the requirement to carry out administrative procedures partly in Bangalore and partly in Mumbai. NCBS is now a mature, well-functioning institute with great awareness of the requirement to observe TIFR and DAE administrative processes meticulously. We suggest that NCBS management should be allowed to enjoy a greater degree of independence, in both hiring and purchasing procedures, while recognising that very large purchases and the most senior hires may still require a two-stage procedure. In relation to TIFR as a whole, we recommend the TIFR Council consider a model in which (like many other large, multi-site organisations it appoints a TIFR Director-General, in charge of the top-level central administration, and that each of the other Centres, including Colaba, have a Director who runs the local management, administration and research and reports to the Director General. A structural move in this direction may profit Colaba, Hyderabad and TIFR in general by allowing the Director General to more easily gain a TIFR-wide view of important issues and the Centre Directors to take care of the more detailed locally important matters.
- In our opinion, NCBS is an extremely valuable part of the TIFR system, having raised the TIFR profile in the life sciences to complement its previous international renown in mathematics and the physical sciences. It is very important that TIFR support is maintained in a way that enables NCBS to grow and thrive, continuing to engage in, and sometimes lead, initiatives of national and international significance.

Detailed advice on some important issues for NCBS in future

NCBS impact

NCBS has had enormous impact in its fundamental research areas and is among the leading institutions, not only in India but also in the world. Considering that it is a small institution established only about 30 years ago, its effective impact has been huge in terms of quality and quantity of science produced. They have published high quality papers and generated a large number of excellent graduates in biology. NCBS has shown vision and foresight in building core scientific facilities as good as the best in the world. Academic ambience within NCBS campus is a model for pursuit of science in the Indian context. NCBS not only trains excellent scientists who register for PhDs at the Centre, but also the young scientists and students from other institutions in India benefit hugely when they attend the advanced short-term training courses on emerging topics in modern biology, conducted regularly by NCBS faculty members and core facility staff. Through sustained excellence, NCBS has provided notable scientific leadership within and outside India. They have proved to be a top-notch institution in certain areas of fundamental research, and that important feature certainly need to be further nurtured. They have, in a very short time, demonstrated how a national institution can produce scientific research of parity with the best in the world.

NCBS and National research initiatives

The quality and breadth of research at NCBS means that in several areas, NCBS has the capacity to lead the development of national research collaborative initiatives, potentially with international involvement, as one means to create even more national impact without making use of traditional NCBS funding sources. We identify three areas that seem obvious possibilities to us, but urge NCBS faculty to discuss this idea and potentially come up with more, or different, ideas to leverage their interests and capacities.

1. NCBS and a Brain Initiative for India

We believe the time is ripe for a Brain Initiative for India. NCBS has the potential to be a major player and potential leader of the Initiative.

The Initiative should have a large vision. It should involve multiple governmental and private stakeholders, researchers and institutes/centers nationwide; span multiple levels of analysis including brain development, function and disorders; include diverse and cutting-edge approaches including modern neuroanatomy, neurophysiology, genetics, stem cell biology, animal models, and computation; be scalable as well as seed new technologies; have the potential to build human capital for research; and be recognized as unique in the international sphere. We believe a project of this scale and scope is achievable in India.

Brain disorders are crippling for afflicted individuals and their families: according to the WHO, the disease burden of brain disorders for India, calculated as disability-adjusted life years (DALYs) is highly significant. As the population ages and several other conditions become chronic and manageable, brain disorders and diseases are expected to overtake heart disease and cancer worldwide as the most debilitating of human diseases. Brain diseases cannot be

understood mechanistically without basic science and data. For example, systematic high resolution datasets of the developing human brain will provide crucial and unique baseline information on myriad genetic and environmental effects on brain development.

Other countries recognize the growing disease burden of brain disorders, and the importance of efforts involving basic science, clinical science and therapeutics development as crucial future pillars of brain research. The US Brain Initiative emphasizes tool development for neuroscience as an important component. The European Brain Initiative focuses on building computer models of brain circuits. The Japanese Brain Initiative focuses on marmoset models for brain research and brain disorders. The Chinese Brain Initiative will study macaque monkeys as models for understanding the human brain.

We suggest that the Indian Brain Initiative should focus on human brain development and disorders. This will be a unique, and uniquely important effort, which NCBS (and inSTEM) are in a special position to lead. It would include basic science and technology, which would enable obtaining, visualizing and analyzing multi-scale data from molecules, cells, tissue, animals and humans. The ADBS collaboration between inSTEM, NCBS, NIMHANS and CMC provides a model for how the disease component of the Initiative can be structured, and also the core leadership which might organize the Initiative. In outline, specific components of the Initiative could include:

- Human brain development: anatomical and gene expression analyses of fetal, postnatal and adult brain. Tools: anatomical sectioning, staining, digitization, high throughput large-scale databanks, image processing and machine learning analyses [NCBS, TIFR, inSTEM, NIMHANS, IIT Madras]
- Phenotyping, NGS and GWAS studies of developmental brain disorders, starting with ADBS cohorts for schizophrenia. Future diseases can include autism, or Alzheimer's disease. Tools: sequencing, statistical genetics, systems biology, computation, anatomical and gene expression analyses of postmortem human brains, large scale phenotyping platforms. [NIMHANS, NCBS, inSTEM, TIFR, CMC Vellore, AIIMS, NIGIB, IITM, other IITs]
- Model systems for understanding disease biology: ESC, iPSC-derived human neurons, mouse, rat, fly worm. Tools: genome engineering, electrophysiology, high resolution multiphoton imaging, optogenetics, circuit analysis of function and behavior, computation. [NCBS, TIFR, NBRC, IISc, IITM]
- Therapeutics development: existing and new medicinal chemistry, human neuron and animal model test-beds. [Partnerships between pharma, systems biology and drug development groups in research centers and IITs, CCAMP].

We hope and expect that multiple government agencies and ministries including DBT, DST, ICMR/Health and IT would participate in this decade-long, transformative project.

2. An Indian Biodiversity, Ecology & Evolution initiative

The advisory committee strongly endorses the plan of NCBS leadership to increase investment in documentation of biodiversity and biodiversity science at NCBS, building

towards and contributing to a national initiative in biodiversity dynamics, with goals of aiding India to achieve sustainability and slow the drastic rate of biodiversity loss in the country.

India is one of the most biodiverse countries on the planet and scientists now recognize that global loss of biodiversity is one of the key consequences of climate change, pollution and overpopulation. With significant environmental and physiographic variation, from extensive coastal environments to the Himalayas and biodiversity hotspots like the Western Ghats, India has many species found nowhere else on earth and harbors some of the last populations of species that have gone extinct outside the country. As a result of extensive and ongoing biodiversity loss, many countries are investing in efforts to monitor biodiversity and sustain biological collections that allow scientists to document and monitor biodiversity over space and time. Scientists are employing diverse technologies, from remote sensing to genomics and computational biology, to predict the consequences of climate change on biodiversity and to better manage the already ongoing loss of biodiversity.

Excellence in biodiversity research and outreach at NCBS: NCBS is prepared to take a leadership role in efforts to monitor and predict the dynamics of biodiversity across India and South Asia. Both in terms of personnel and in nascent infrastructure in the form of biodiversity collections, NCBS is poised to contribute to solutions for India's emerging biodiversity crisis. The Ecology & Evolution Group at NCBS is comprised of ~8 faculty who span a broad range of disciplines, from ecosystem ecology to population genetics and evolutionary biology to behavioral ecology and neuroethology. As a group, through their research and outreach, they have brought the biodiversity of India to international prominence and to a broad, inclusive public audience. Together they have given NCBS a major voice in the national dialogue on issues of biodiversity and sustainable coexistence and thereby provided critical insight into a core foundation of Indian society. This is a unique effort of outstanding quality and the NCBS scientists involved are working with others on a national "Biodiversity Mission." This is a project of great importance for India, with the potential for immense impact on environmental and conservation policy. They have also put in place the beginnings of critical biodiversity infrastructure at NCBS, in the form of natural history collections and associated online metadata (see separate section below). A key component of their broad impact is the easy accessibility of the biodiversity specimens now cared for by NCBS to other researchers. Such access to Indian biodiversity is unprecedented and a major catalyst of new research on Indian biodiversity.

Individual labs within the Ecology & Evolution Group have generated substantial grant funding, and considerable numbers of awards, often coming from international sources. For example, Profs. Sane and Ramakrishnan were elected to the Indian National Science Academy in 2019 and 2020, respectively. Prof. Uma Ramakrishnan is now a Welcome Trust DBT India Alliance Senior Investigator. Prof. Mahesh Sankaran was awarded the 2019 SERB Distinguished Investigator Award. Prof. Deepa Agashe is a Wellcome Trust/DBT India Alliance Intermediate Fellow and in 2019 won a Special Topics Network Grant from the European Society for Evolutionary Biology. These are just a few examples of the uniform prominence of this research group and illustrates how such a small group can have a disproportionate impact. All labs in this group participate actively in public outreach, an important activity because animals, plants and biodiversity naturally appeal to a curious public.

The future of the Ecology & Evolution Group should build on this excellence and position themselves to lead in the area of biodiversity studies across India. A major consideration is strategic hiring at NCBS and how to complement existing strengths in biodiversity studies and behavior. Now that NCBS and the Ecology & Evolution Group are mature, strategic hires in specific areas, while keeping an eye on top talent, may be more effective than broad multidisciplinary searches. The Ecology & Evolution Group could benefit from enhanced computational biology and data science at NCBS, which would augment ongoing research in genomics and large-scale ecological analyses. The group is well-positioned to generate academic leaders who could lead and inspire national initiatives in biodiversity studies. Working with NGOs in the Bangalore area and beyond, there are substantial opportunities for national initiatives in biodiversity inventory across India, some of which have already begun. The Masters training programme organized by this group is exceptional and is described in the section of this report devoted to PhD and other training programmes. It can be an important component of an expanded initiative in this area.

Expanded and well-staffed biodiversity repository: The biodiversity repository at NCBS is another area of potential growth that could aid the nation's efforts to document and monitor its biodiversity (see section in Facilities). Staffing for the repository and establishing funding for its long-term maintenance should be important considerations in an effort to provide easily accessible, up-to-date and comprehensive data on India's biodiversity. The Biodiversity Repository is rightly considered critical infrastructure for NCBS, facilitating cutting-edge research and public outreach. Key issues for the future of the Repository include scaling up and long-term stability. Natural history collections by necessity increase their value with time, as they record changes in biodiversity and environmental quality over time. Permanent staffing of the repository is essential. Intellectual leadership and oversight of the Repository should be established so that the directions and impact of the Repository can be guided with long-term goals in mind. A searchable, online database with links to other global biodiversity databases, should be established to enhance its value and provide environmental context for the specimens being curated. Modest growth of the collection is essential, especially as India's ecosystems and faunas are changing rapidly due to global change. Establishing baselines now for Indian communities of insects and other organisms will be critical for measuring environmental change into the future. A recent (2020) report by the US National Academy of Sciences calls for greater support, ongoing growth, digitization and global networking of the world's natural history collections. Thus, similar efforts by NCBS would be consistent with growing calls for continued collecting, networking and increased support for natural history collections worldwide. A similar NAS report in 2014 endorse the continued relevance and critical contributions of field stations and marine laboratories, highlighting the importance of NCBS's cadre of field stations (see facilities).

NCBS is noteworthy – indeed, unique - among life sciences institutes globally in investing in ecology, evolution and biodiversity. Their very strong performance in this area and their ability to bring to global awareness the plight of Indian biodiversity recommends continued investment in this area.

3. Computational and Theoretical Biology initiative.

It is now widely recognized that modern Life Science is an increasingly quantitative enterprise and its future progress is critically dependent on the ability to analyse and interpret extensive data and formulate predictive theories that can guide experimental study of complex biological phenomena. For example, the fundamental problem of understanding genetics of complex phenotypes connects the study of molecular and cellular mechanisms with the analysis of genomic and clinical data: increasingly such laboratory and clinical studies engage not only the computational muscle of bioinformatics, but also mathematical models and ideas from statistical physics. Needless to say, understanding genetics of complex traits (e.g. schizophrenia or predisposition to cancer) is a fundamental problem of profound medical relevance. Another fundamental problem of great societal relevance concerns understanding the diversity of species: what are the ecological and evolutionary mechanisms that generate and maintain diversity? The problem is sometimes stated as the "Paradox of Plankton" pointing to the seemingly inexplicable diversity of motile marine microorganisms all competing for resources, without emergence of a single "winner". This field is now supercharged by genomic and meta-genomic data, but understanding will not emerge without modeling and theory of eco-evolutionary dynamics, which is now being developed with the fresh injection of ideas from dynamical systems and statistical physics. Life science is an increasingly interdisciplinary effort linking Biology with a spectrum of disciplines from Physics to Computer Science. The future of life science therefore requires a scientific work force that is fluent with quantitative and computational ideas, tools and technologies and can communicate across the existing disciplinary divides.

Luckily, developing new Quantitative Biology goes hand in hand with building interdisciplinary efforts and training the next generation of scientists. This challenge also presents and outstanding opportunity. NCBS is strategically positioned to advance the agenda of Quantitative Biology both nationally and on the global scale. Emphasis on fundamental research has led to the early emergence at NCBS of a computational and theoretical biology centre of excellence deeply integrated into the institute research effort and culture. Bioinformatics efforts at NCBS not only have the capacity to analyse data, but to innovate, advancing the field by developing new methods and algorithms. There is also a distinct potential for growth of computational and theoretical neuroscience in conjunction with molecular, cellular and systems neuroscience. Altogether, excellence of the existing computational and theoretical biology research at NCBS provides an exceptionally strong foundation for growth in the context of building connections with existing and emerging research groups within TIFR and elsewhere in India and beyond. NCBS, leveraged by collaborations that it could seed, lead and facilitate, is within a striking distance, i.e., essentially on a par with the outstanding computational and theoretical biology efforts at Princeton or MPI. International recognition of the existing effort is evidenced by the continuing support from the Simons Foundation. International reputation in its turn is helpful both in attracting talented foreign students and postdocs and retaining Indian talent at all levels.

NCBS faculty has many ideas to develop and advance this Quantitative Biology scientific agenda. The fundamental problem of complex phenotypes mentioned above, bridges scales of biological phenomena from genes and molecules and their dynamics on subcellular scales to population genetics and evolutionary dynamics on the largest scales. Computational tools are central to analysing genomic and other experimental and clinical data, readily linking to

translationally relevant research. Dealing with the large volume of data in support of experimental efforts requires well-trained professional staff. Yet, bioinformatics goes far beyond routine, as development of novel computational inference approaches is an intellectually exciting frontier of fundamental and interdisciplinary research. As an example, one could point to the recent development of a new method of protein structure prediction which used the Statistical Physics-inspired "maximum entropy" (or "Inverse Ising Model") approach to predict intra-molecular interactions from the observed correlations in the sequence of evolutionarily related genes. Many other impactful computational inference methods will surely emerge through the convergence of interdisciplinary thought.

Understanding complex phenotypes also involves relating subcellular mechanisms to biological function on tissue and organ scale, in particular in the context of development. Making sense of complex interdependences calls for mathematical models with the challenge of identifying the relevant variables that capture the essence of the phenomena in a predictive way. The culture of "phenomenological modeling" imported from theoretical physics together with dynamical systems theory and ideas from Soft Condensed Matter physics prove useful. This is evidenced, for example, by the impact that the collaboration between two Max Planck institutes in Dresden - the MPI for "Physics and Complex Systems" and the MPI for "Molecular Cell Biology and Genetics" – has had in understanding cellular and tissue-wide processes underlying Drosophila development. The NCBS group of theoreticians have already established a net of collaborations with cell and developmental biology labs on their campus as well as on the TIFR/Colaba campus and the IIS. We confidently expect that they will achieve success at least to match the Dresden collaborations, while working on different and innovative biological systems. Furthermore, going beyond the established practice of biological modeling based on differential equations, Simons' Center theoreticians at NCBS have pioneered creative use of discrete mathematics in modeling cellular and developmental processes, harnessing ideas from theoretical computer science.
This has created bridges connecting computational and theoretical biology at NCBS with computer scientists elsewhere at TIFR and (potentially) with the nascent theoretical computer science at ICTS. Three-way interaction between biology, theoretical physics and computer science has the potential to revolutionize quantitative and computational biology. TIFR as an incubator of fundamental research is in a unique position to make such a revolution happen. It would require stable and flexible support and the hiring of (potentially joint) faculty and more institutional encouragement for internal and external collaborations

Last but not least, we note the importance of inter and cross disciplinary training, bringing biology to physics and computer science audiences and vice versa. Here NCBS – often in collaboration with ICTS - has already established an extensive portfolio of workshops and schools that advance the agenda of Quantitative Biology while training the suitably versatile life scientists of the future.

In conclusion we note some specific aspects and needs of the computational and theoretical biology initiative we suggest to pursue. As this effort connects with the data analysis needs of multiple experimental labs, much of the computational support of this kind should be provided by the technical staff of a suitably organized "bioinformatics support centre". This would allow researchers to focus on innovation and advancing the field. "Theorists" also have extensive networks of collaboration: they therefore become valuable agents of cross-

institutional (and international) bridge-building but as a consequence require greater support and flexibility of travel.

NCBS Core Facilities

One of the critical elements required for the long-term success of an institution such as NCBS is its ability to stay current, with ready access to state-of-the-art equipment to service the evolving needs of the various research programs. Properly managed core facilities are essential not just for science at NCBS, but have tremendous potential for national impact when they are made accessible to other educational institutions and centers in the research ecosystem. There are now no internationally competitive research-performing organisations that do not rely heavily on core facilities, with state-of-the-art equipment and core facility staff who have the knowledge and experience to make the equipment available to non-expert users. Core facilities are a key enabler of modern, multidisciplinary, research initiatives and we compliment NCBS on organizing these.
There are over a dozen excellent core facilities at NCBS that span an impressive intellectual range from structural and cell biology to ecology. The facilities include cores that house state-of-the-art microscopes for imaging cells and molecules. There are tools for high throughput sequencing, next generation genomics, biophysical characterization and facilities for generating transgenic mice. There is a unique ecology and biology Station managed by NCBS for national access. The recent installation of an advanced electron microscope has enabled the creation of a first-of-its-kind national facility for cryo-EM in India. The newly constructed BSL-3 facility specially designed to study the pathogens that cause tuberculosis and malaria is a significant achievement relevant to finding cures for diseases prevalent in India.

The creation and maintenance of core facilities at NCBS poses a special challenge given the diverse scientific portfolio of the principal investigators. The instrumentation is typically expensive and not commonly available at other institutions in the country. NCBS has been exemplary in terms of sharing these resources nationally; over 200 institutions in India benefit from the instrumentation that is available at NCBS or through C-CAM.

Aside from the essential requirement to continue to provide state-of-the-art equipment through NCBS budgets, to the facilities, it is difficult to overemphasize the importance of investing in recruiting and retaining skilled staff to maintain these state-of-the-art core facilities. Operating complex instrumentation in a way that optimizes performance and allows the training of new users is essential for success of the research at NCBS as well at the institutions that take advantage of the resources at NCBS. As life science research becomes more multi-disciplinary, the proportion of non-expert facility users increases, making trained, experienced, expert staff essential for their use. The review panel noted that key staff employed in many of these facility cores do not have stable, long-term appointments but rather outsourced positions. Investigators that the panel interviewed expressed concern that this is causing anxiety about job security among the staff, and that staff departures for more stable positions at other institutions/organisations can become a serious threat to the quality of the science conducted at NCBS and more broadly to the large number of external facility

users from all over India over the long-term. This highly trained manpower plays an essential role in ensuring that the core facilities function at the highest level, enabling science at NCBS and for all other academic institutions which have no other way of accessing high-end equipment. Downtime of core facilities and equipment in the absence of these staff and the need to then rebuild technical and scientific capacity damages the trajectory of research productivity. The review panel strongly recommends that TIFR and NCBS management, through DAE, create permanent positions for these staff scientists who are scientifically uniquely skilled and valuable to academia and industry within and outside the country.

PhD and other training programs of NCBS

NCBS is one of the most vibrant campuses in the country. Along with 35 faculty members, NCBS has 184 Post-docs, 247 students (PhDs and Integrated PhDs) and 217 junior/senior research fellows, many of them also registered to obtain PhD training with an affiliation to an Indian University. There also 17 students of MSc (Wildlife) which is a unique program. Taken together, this bring the number of individuals going through different long-term training programs to 565, which means more than 16 per faculty member at a given time. This is very impressive number. In spite of this large quantity, the quality of training is one of the best by any standard in international context. This is evident from the fact that students trained from NCBS do very well. Most of them go on to build a successful scientific research career. The whole programme works extremely well but we highlight one particularly striking example. A masters programme in Wildlife Biology and Conservation was launched in 2004 as a unique and original initiative in India (and Asia). By 2016 there were 89 graduates of the programme, and these Masters students had generated 65 peer-reviewed publications, a remarkable ratio for a Masters programme. The programme continues to educate roughly 8 students per year on average. Roughly 45% of the graduates have gone on to do further studies in universities around the world and have produced roughly 150 publications. The remaining 55% work as independent investigators or in NGOs on wildlife and conservation issues, collectively garnering a number of prestigious awards. 37 of the 39 who are carrying out a PhD, many of them abroad, have chosen to work on Indian wildlife populations. These are quite remarkable numbers and reflect the impressive quality of teaching, and the careful selection of students, to join the NCBS programmes in general.

In addition, NCBS is also known for its quality workshops and scientific meetings, symposia, etc. To name a few regular ones of international repute, Bangalore Microscopy Course, Computational Approaches to Memory & Plasticity, Benny Shilo course on Developmental Biology, etc. There are over a dozen quality training programs like these, every year. In fact, NCBS has acquired a highly reputed position in carrying out international quality training workshops, courses, etc., on a regular basis. This brings Indian PhD students and postdocs into contact with individuals of highest scientific repute, which in turn instills quality and confidence in our students and young scientists.

In addition to its remarkable contribution to quality research, NCBS has created a brand value of its training programs. The fact that NCBS has a campus with accommodation possibilities for many of the PhD students allows the development of a community spirit that enables younger PhD students to benefit from the example set by the more experienced members, further helping them to learn maximally not only about the intellectual aspects of scientific

research but also the more practical issues that must be faced in actually pursuing a research project to a successful conclusion; this means both publication of results and graduation as a doctoral fellow. There is no doubt that it is a major contribution which is of very high societal impact. This campus life, the culture and encouragement provided to the young students at NCBS, deserves to be praised.

Retirement age structure

In a centre with a limited number of staff, the age structure of the faculty and succession planning require a strategy to ensure stability and continued productivity. NCBS has had staggered recruitment over its 25 years of existence. However, the retirement age of 60 and the small number of faculty (currently 35) means that a number of senior faculty will retiring in the near future. In institutions in other parts of the world, they would be expected to be productive and play leadership roles for at least an additional 10-15 years. This is an important and unnecessary loss or phasing out of highly skilled scientists, who are contributing maximally to science and to mentoring at this stage of their careers. This is not unique to NCBS, but is applicable to all governmental scientific institutions in India (with varying ages of retirement of 60, 65 or 70 years depending on the field of practice, position and responsible ministry). Given demographic shifts, it is feasible that the government will consider whether the retirement ages should be increased. Pending that uncertain decision, it is important that TIFR and NCBS consider approaches that allow for seamless continuation of scientific contribution, without needing to take each person as a special case. This is especially important for these scientists who take up national leadership roles in large-scale collaborative projects in areas such as biodiversity, neuroscience, etc. In order to be effective in developing such projects, the scientists involved must have established reputations and this generally means that only people over the age of 50 can begin to take leading roles. To lose such a person before the projects are stably established is very destructive and requires that, in some way, exceptions must be made to normal retirement procedures.

Particularly at NCBS, given the high calibre of the staff and their unquestioned capacity to contribute to all the goals of NCBS, the Bangalore Bioscience Cluster, TIFR in general and national research-based intitiatives, the Review Committee recommends that mechanisms be agreed such that retiring scientists who wish to continue to work be provided with a pathway that enable their continued participation in the scientific, organisational, educational and outreach activities of NCBS. The questions of space, access to students and facilities and emoluments, whether as salaries or the ability to raise personal funding through extramural grants, should be agreed and predictable. Human scientific capital as found in premier institutions in India is a national resource and its maximal utilization is a collective national responsibility which should be enabled by the TIFR Council and institutional administration.

Final conclusions

NCBS is a dynamic, productive research institute that is competitive and internationally well-known in the life sciences. Aside from its intramural research excellence, NCBS is an active

contributor to the TIFR system and a motor for the development of many exciting initiatives both in Bangalore and nationally. NCBS is a generous contributor to many scientific, training and networking initiatives in India, many of which were initiated by NCBS and through which many Indian scientists benefit. NCBS is truly an institute of which India can be proud.

Annex1

NCBS cross-institute TIFR collaborations

NCBS-TIFR Mumbai collaborations:

1. Jayant- G Krishnamurthy: Study of time resolved FRET in protein folding
2. Jitu-G Krishnamurthy Study of homo-FRET in membranes
3. Jitu-Sudipta Maiti- Study of membrane organization of cells activated by serotinin
4. Maithreyi – Madan: Mechanics of deformation of tissue during dorsal closure.
5. Jitu- Roop: Role of cholesterol in recruitment of kinesins.
6. Vinoth- Debasis Das - Molecular basis of regulated vesicular secretion
7. Shona-Vidita: Stress and BDNF in the hippocampus vs Amygdala
8. Sandhya Koushika- Sowdhamini - Kinesin-3 Motor UNC-104/KIF1A binding to Cargo.
9. Upi-Shubha: looking at role of electrical activity of subplate neurons in axon guidance, which is altered in Lhx2 mutants. Paper in preparation.
10. Upi-Shravan Hanasoge: Discussions of big-data and AI analysis, after some initial ideas and advice this didn't go further.
11. Ranbir Das -Sudipta: Studying role of decoy nucleus in Protein folding
12. Shachi Gosavi-Ranabir Das- Sudipta Maiti-: biophysical studies on ubiquitin

2) NCBS-ICTS

1. Sandeep-Shashi-Vijay Krishnamurty: Mechanics and active flows of temperate phage infection fronts within bacterial colonies
2. Sandeep-Sunil-Vijay Krishnamurty: Spatial organization of emergent metabolic states in growing yeast colonies
3. Shashi - Vijay Krishnamurty : collective dynamics in synthetic active matter
4. Shashi - Vijay Krishnamurty : phage - bacteria infection dynamics
5. Axel Brockman- Pallab Basu : Analyzing honey bee and fly walking trajectories

NCBS-TIFR-H

1. Vinoth- MK- Laser induced high energy electrons as a table top EM source

NCBS-TCIS

1. MK Mathew – Monika Vig, TCIS on store-operated calcium entry.
2. MK Mathew – Adish Dani, TCIS on olfactory receptors in the vomeronasal organs