Final Report of the ESF Science Meeting

Ecological Complex Systems: Stochastic Dynamics and Patterns

1. Summary

The workshop took place at the beautiful *Città del Mare Hotel and Resort,* near the village of Terrasini, in the neighbourhood of Palermo, Sicily from July 22 to July 26, 2007. The workshop had its focus on the comprehension of noise's role in the dynamics of ecological complex systems, which are very sensitive to initial conditions, deterministic external perturbations and to fluctuations always present in nature.

The aim of the workshop was to discuss noisy non-equilibrium processes emerging in modelling the dynamics of ecological systems and to address the mechanisms of spatio-temporal pattern formation in ecology both from the experimental and theoretical points of view. The lectures of the workshop had a marked interdisciplinary character.

The workshop gathered 40 participants from 10 countries, including 23 speakers, 4 young researchers with short talks and 3 chairmen. The small scale and intense workshop had 23 speakers from Universities and Research Institutions of Israel, Germany, Greece, UK, Poland, Spain, Switzerland, Russia, USA and Italy. The final list of speakers and participants has been submitted online through the ESF website. The workshop brought together theoreticians, modellers and experimentalists, to establish a common language and exchange new ideas and recent developments in the field of ecology with the specific focus on the stochastic dynamics and spatio-temporal pattern formation in population dynamics.

The workshop was organized in 5 sessions, a round table on "Cancer growth dynamics and open problems" and a poster session. The discussion after each presentation made the workshop into a interesting scientific event with a real stimulating and participating atmosphere. Particularly it is worthwhile to mention the round table on Cancer growth dynamics, which was characterized by a passionate discussion about open problems on this interdisciplinary research subject.

The workshop was financially supported by STOCHDYN programme of ESF, the University of Palermo, the "Dipartimento di Fisica e Tecnologie Relative" of Palermo University, and the "Azienda Autonoma Provinciale per l'incremento turistico (AAPT)" of the Regional Province of Palermo's city.

Detailed information about the event is available in the website of the workshop: http://gip.dft.unipa.it/workshop_ECS_Pa07/, which will be updated and kept active in the foreseeable future.

2. Description of the scientific content and discussion

The comprehension of noise role in the dynamics of nonlinear systems plays a key aspect in the efforts devoted to understand and model complex ecological systems. Specifically, the interaction between noise and nonlinear determinism in biophysical systems and ecological dynamics adds an extra level of complexity compared with the largely stochastic dynamics of, say, economic systems or the largely deterministic dynamics of many physical and chemical processes. The comparable importance of deterministic and stochastic forces makes biological and ecological dynamics unique. Understanding ecological systems indeed may be enhanced by analysis of their complex nature. The effects of small perturbations and noise, which is ubiquitous in real systems, can be quite difficult to predict and often yield counterintuitive behavior. Even low-dimensional systems exhibit a huge variety of noise-driven phenomena, ranging from a less ordered to a more ordered system dynamics.

The noise through its interaction with the nonlinearity of the living systems can give rise to new, counterintuitive phenomena like noise-enhanced transport, noise-sustained synchronization, noise-induced transitions or noise-enhanced stability, stochastic resonance, noise delayed extinction, temporal oscillations and spatial patterns. To describe complex ecosystems, therefore, it is fundamental to understand the interplay between noise, periodic and random modulations of environment parameters and the intrinsic nonlinearity of simple models of ecosystems and to understand spatio-temporal dynamics. It is becoming apparent that fluctuations and noise are essential ingredients of life processes. It is important to mention that ideas borrowed by statistical mechanics, nonlinear dynamics, critical phenomena and non-equilibrium physics have considerably contributed to the understanding of ecological pattern formation processes and its complex dynamics.

In order to discuss different topics of ecological complex systems, the workshop was organized in 5 sessions, one round table and one poster session:

- Bioinformatics
- Interdisciplinary Physics I & II
- Population Dynamics
- Self-Organization and Patterns in Ecosystems
- Motion of Proteins and Motor Protein
- Round Table: Cancer Growth Dynamics and Open Problems in Ecosystems
- Poster Session: Interdisciplinary Physics

Bioninformatics

This session was the first of the workshop and was opened by Rosario N. Mantegna, who presented a widespread analysis of potential RNA secondary structures located in complete genomes of viruses. A statistical characterization of these sequences together with a comparison with that obtained by a Bernoullian null hypothesis has been shown. Complexity and organization in the primary structure of the human DNA was the subject of the lecture by Astero Provata, who addressed the organization of coding and noncoding segments in all chromosomes. Ioana Bena described his theoretical work on the universal features in quasispecies punctuated evolution by using the random Eigen model and by finding universal scaling behaviour of the leader-genotype probability distribution function. Bacterial intelligence: from Physics to Cybernetics was the title of the lecture presented by Eshel Ben Jacob. By reviewing his far-reaching work on this subject, Ben Jacob showed the strikingly beautiful organization of the patterns that bacteria form when grow in a Petri disk by reflecting, in a sense, their underlying social intelligence. He proposed a striking hypothesis: bacteria use their genome computation capabilities and genomic plasticity to collectively maintain exchange of meaning-bearing chemical messages (semantic), and dialogues (pragmatic) for purposeful alteration of colony structure and even decision-making, features that are associated with intelligence. Fabrizio Lillo closed the session by presenting his investigation on the compression of information in bacterial

genomes. He showed his investigation on the properties of overlapping genes in 58 bacterial species evaluating neutral and selective mechanisms of evolution.

Interdisciplinary Physics I & II

Werner Ebeling opened this session by presenting the model of active Brownian dynamics to describe the motion of swarms of animals. The dynamic and stochastic bifurcations between the rotational and translational modes were analyzed, by discussing the effect of other models of interactions, like Morse forces and hydrodynamic interactions. The dynamics of a FitzHugh-Nagumo system driven by a periodical signal in the presence of a coloured noise was described by Davide Valenti. Michele Tumminello in his talk showed that the Kullback-Leibler distance is a good measure of the statistical uncertainty of correlation matrices estimated by using a finite set of data. Alessandro Fiasconaro reported the effects of noise in a cancer growth model in the presence of spontaneous fluctuations and periodic treatment, by finding the noise enhanced stability, the resonant activation and the stochastic resonance effects. The response of an integrated system, for the study of complex phenomena monitored by gas Radon was discussed by Fabio Vizzini. The investigation of the influence of gating charge effects on the channel noise-induced spontaneous spiking activity of excitable membrane patches within a stochastic Hodgkin-Huxley modelling was discussed by Gerhard Schmid. Aneta Stefanovska reported on the cardio-respiratory synchronization transitions at high altitudes, by considering the implications for the pressurization of aircraft. Finally Francesc Sagués presented the noise-based selection mechanism of Turing vs. Hopf bifurcations in a photosensitive chemical medium.

Population Dynamics

Leonard Sander opened this session with a lecture on fluctuations and dispersal or migration rates in population dynamics. He showed by an agent-based model how the fast species dominate or coexist with the slow species because of the presence of fluctuations, contrarily to the deterministic dynamics, in which the slow species always dominates. Olga Chichigina presented a noise model with memory, which describes the population cycles in small rodents (lemming) of the north regions, like North America and Siberian tundra. By considering a spatio-temporal model in which phytoplankton populations are limited only by light and a nutrient, Alexey Ryabov showed how the distribution of a phytoplankton monoculture becomes bistable. Alexander Dubkov discussed the transient dynamics of the Verhulst model perturbed by arbitrary non-Gaussian white noise. His theoretical findings, in the case of Lévy stable noise, show the existence of trimodal probability distribution which transforms to bimodal in asymptotics.

Self-Organization and Patterns in Ecosystems

This session was opened by Sorin Solomon, who reported on his recent theoretical work on a series of models of population dynamics which take correctly into account the stochastic and spatially extended character of these systems and which lead to predictions closer to the singular, fractal, localized character of growth and survival in real systems. Michel Droz described by analytical (mean-field like) and numerical approaches the dynamics of a single-species population evolving in a two-dimensional space by showing the complex dynamical behaviour due to competition between different time-scale phenomena. Stamatios Nicolis presented the mechanism underlying collective decision-making and self-organization in social insects. Mean field models incorporating the principal sources of cooperativity were developed and complemented by stochastic simulations. The detection of complex networks modularity by dynamical clustering was discussed by Alessandro Pluchino.

Round Table: Cancer Growth Dynamics and Open Problems in Ecosystems

This very stimulating round table on cancer growth dynamics was opened by Dr. Claudio Tripodo, a physician expert in cancer biology research. His clear and stimulating talk on "An insight into cancer biology" opened a passionate discussion between all the participants of the workshop, focusing on how Physics can help Biology and vice versa how Biology and Medicine can stimulate and provoke Physics with their complexity. Particularly the open panel discussion was enriched with the short programmed talks by Leonard Sander on "Models of malignant brain tumor", Sorin Solomon on "Growth of network" and some peculiarities of the immune system, and finally by Eshel Ben Jacob who pointed out that this round table was a sort of sysnthesis of all previous sessions. By discussing firstly on intra and inter gene problems, then by analyzing ecosystems and finally by ending with cancer growth dynamics.

Motion of Proteins and Motor Protein

Martin Bier opened on July 25 this session with a lecture on the roles of energy and entropy for a stepping motor protein. He presented a Brownian Stepper model that can quantitatively account for back-stepping measured rates by experimentalists. For the motor protein kinesin there are indications that the power stroke derives from the entropically driven coiling of the 30 amino acid neck linker that connects the two legs of kinesin. Andrey Chikishev presented then a lecture on the low-frequency vibrational motions in proteins, by discussing the underlying physical mechanisms. He proposed models of the low-frequencies motions in specific protein molecules and analyzed their possible effect on the protein functioning. Sighart Fischer closed the session with a lecture on random matrix theory with applications in biology..

Poster Session: Interdisciplinary Physics

Here are reported all the posters presented at the workshop:

P. Caldara, A. La Cognata, B. Spagnolo
Role of the multiplicative noise in the lifetime of metastable states

Carlo Casarino and Gaetano Liborio Aiello
Volume Transmission in Neuronal Networks: A Work-Hypothesis on Stochastic Dynamics of Metabolic Cost

Antonio Cimino, Adolfo Cimino, G. Giunta, A. Oieni
Hydrogeological Risk Assessment Based o Natural ad Anthropic Events

C. Coronnello, S.Miccichè, V.Romano, S. Sbacchi, R.N. Mantegna
A Gene Ontology Analysis of patients affected by Autism disease

A. Fiasconaro, Werner Ebeling and Ewa Gudowska-Nowak
Active Brownian Motion in a Ratchet Potential

R. Grammauta, D. Molteni, G. Basilone, A. Bonanno, S. Aronica, G. Giacalone, I. Fontana, M. Zora, B. Patti, A. Cuttitta, G. Buscaino, S. Mazzola
Linking ecological and physical features in the Strait of Sicily preliminary results of air - sea interaction

N. Pizzolato, D. Valenti, D. Persano Adorno, B. Spagnolo
Stochastic modelling of imatinib-treated leukemic cell dynamics

A. La Cognata, P. Caldara, B. Spagnolo
Lévy flights in a metastable potential

L. Cuccia, C.A. Hidalgo, A.L. Barabasi
Mapping business relations from an evolutionary perspective

3. Assessment of the results, perspectives and future impact

The proposed workshop aimeed to gather together scientists studying different ecological structures ranging in space and time scales from microscopic bacterial growth to fish dynamics, cancer growth, and to rainforest patterns and exhibiting temporal regular and irregular oscillations which may be due to the intrinsic dynamics or caused by external sources and modulated by noise. Scientists working on ecological problems with different points of view and backgrounds had the opportunity to assess the current status of the research, to determine the problems to be attacked theoretically and numerically and to determine the best theoretical and numerical models to be used in each particular case.

From the experimental point of view recent advances in the fields of bacterial growth, RNA structure in virus genome, tumour development, social behaviour in animal groups, competing species in various spatial geometries, epidemics spreading, and other ecological topics has been presented.

One of the main issues of the workshop was to briefly review noisy nonequilibrium processes useful to describe the dynamics of ecological systems and to address the mechanisms of spatio-temporal pattern formation in ecology both from the experimental and theoretical points of view, aiming to understand the dynamical behaviour of the ecological complex systems by the interplay between nonlinearity, noise, random and periodic environmental interactions. Discovering the microscopic rules and the local interactions which lead to the emergence of specific global patterns or global dynamical behaviour are indeed actual challenge problems in ecological complex systems.

During the presentations and the discussions of the workshop the following specific topics were addressed: self-organization in ecosystems, fractal topology and self-similar structures, power laws and scale-free structures, cooperative phenomena, noise induced transitions, patchiness, clustering and heterogeneity, percolation phenomena, effects of initial and boundary conditions, external control of pattern formation, noise induced phenomena and stochastic dynamics of out of equilibrium systems.

A broad range of new results on ecological complex systems were reported establishing the state of the art of the field. A common feature of the different ecosystems presented at the workshop is the combination of the intrinsic nonlinearity of the biological systems and the random fluctuations always present in nature. Our understanding of complex ecosystems, therefore, needs the methods of the theory of stochastic processes and nonlinear dynamics on the basis of the out equilibrium statistical mechanics and physical laws.

The workshop "**Ecological Complex Systems: Stochastic Dynamics and Patterns**" has succeeded in providing a forum for the exchanges of ideas between experimentalists, theoreticians and modellers and cross-fertilization between the different ecological topics, by contributing essentially in this way to the development of the field.

European Science Foundation Workshop
STOCHDYN Programme

Ecological Complex Systems: Stochastic Dynamics and Patterns

22-26 July 2007
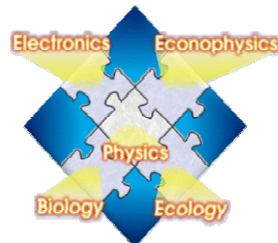## Città del Mare, Terrasini, Palermo, Italy

Workshop Program

Main Sponsor

and cosponsered by:

Università di Palermo

Group of Interdisciplinary Physics

Workshop Program

Chairmen: **Astero Provata, Igor Sokolov and Bernardo Spagnolo**

July 22nd 2007 – Sunday – Arrival Day

18.00 – 20.00	*Welcome Cocktail and Registration*
20.30 – 22.00	*Dinner*

July 23th 2007

8.50 – 9.00	*Opening Session*
	Session: Bioinformatics
	Chairman: Leonard M. Sander
9.00 – 9.40	*Rosario Nunzio Mantegna* RNA secondary structures in complete genome of viruses
9.40 – 10.20	*Astero Provata* *The Human Genome: Complexity and Organisation*
10.20 – 10.50	*Ioana Bena* *Universal Features in Quasispecies Punctuated Evolution*
10.50 – 11.10	*Coffee Break*
	Chairman: Rosario N. Mantegna
11.10 – 11.55	*Eshel Ben Jacob* *Bacterial Intelligence: From Physics to Cybernetics*
11.55 – 12.30	*Fabrizio Lillo* *Compression of information in bacterial genomes*
12.30 – 14.30	*Lunch*

Session: Interdisciplinary Physics

Chairman: Peter V. E. McClintock

15.00 – 15.40

Werner Ebeling
Dynamics of swarms - dynamic modes, attractors and bifurcations
in the active Brownian motion model

15.40 – 16.15

Francesc Sagués, S. Alonso, D. G. Míguez
Noise-based selection mechanism of Turing vs. Hopf bifurcations in a
photosensitive chemical médium

16.15 – 16.30

Davide Valenti
Dynamics of a FitzHugh-Nagumo system driven by a periodic signal in the presence
of colored noise

16.30 – 16.45

Michele Tumminello
Kullback-Leibler distance as a measure of information filtered from multivariate
data

16.45 – 17.00

Alessandro Fiasconaro
Noise Effects in Cancer Growth Influenced by Spontaneous Fluctuations and
Periodic Treatment

17.00 – 17.15

Fabio Vizzini
Response of an integrated system, for the study of complex phenomena monitored
by gas Radon

17.15 – 17.35

Coffee Break

Poster Session: Interdisciplinary Physics

Chairman: Igor Sokolov

17.35 – 18.15

Poster presentation

P. Caldara, A. La Cognata, B. Spagnolo
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Lévy flights in a metastable potential

L. Cuccia, C.A. Hidalgo, A.L. Barabasi

Mapping business relations from an evolutionary perspective

A. Fiasconaro, N. Pizzolato, S. Spezia, L. Curcio, D. Valenti, B. Spagnolo, S. Colazza, E. Peri, P. Lo Bue

Stochastic resonance effect on the vibratory signals of stink bugs

Luigi Tranchina, Maria Brai, Antonio Caruso, Claudia Cosentino

The use of bioindicators (Posidonia oceanica and benthic foraminifera) to evaluate metal pollution in a complex ecological system: marine coastal environment

Poster discussion

18.15 – 19.45

Dinner

20.30 – 22.00

July 24th 2007

Session: Population Dynamics

Chairman: Sorin Solomon

Leonard M. Sander

9.00 – 9.45   *Fluctuations and Dispersal Rates in Population Dynamics*

Olga A. Chichigina

9.45 – 10.15   *Noise with memory as a model of lemming cycles*

Alexey Ryabov

10.15 – 10.45   *Title Bistability of distribution and competition outcome of phytoplankton*

Coffee Break

10.45 – 11.00
Chairman: Michel Droz

Alexander A. Dubkov

11.00 – 11.35   *Verhulst model with Lévy stable noise excitation*

Peter V.E. McClintock

11.35 – 12.20   *Invisible dynamics revealed by noise: application to population ecology*

Igor M. Sokolov

12.20 – 12.55   *Continuum description of a SIR contact infection spread*

Lunch

13.00 – 14.30

Session: Self-Organization and Patterns in Ecosystems

Chairman: Astero Provata

Sorin Solomon

15.30 – 16.15   *Chance as main (only) cause for Survival*

Michel Droz

16.15 – 17.00   *Competition between multiple time-scale phenomena in complex population dynamics*

Coffee Break

17.00 – 17.15

Stamatios C. Nicolis

17.15 – 17.50   *Self-organised communication networks in social insects*

Alessandro Pluchino

17.50 – 18.20   *Detection of Complex Networks Modularity by Dynamical Clustering*

Round Table: Cancer Growth Dynamics and Open Problems in Ecosystems

Chairman: Bernardo Spagnolo

C. Tripodo

18.20 – 18.40   *An Insite into Cancer Biology*

L. Sander

18.40 – 18.50   *Models of malignant brain tumor*

Discussion

18.50 – 19.30

Conference Dinner

20.30 – 22.30

July 25th 2007

Session: Motion of Proteins and Motor Protein

Chairman: Werner Ebeling

9.00 – 9.45	**Martin Bier** *The Roles of Energy and Entropy fro a Stepping Motor Protein*
9.45 – 10.30	**Andrey Yu. Chikishev** *Low-Frequency Vibrational Motions in Proteins: Physical Mechanisms and Effect on Functioning*
10.30 – 11.10	**Sighart F. Fischer** *Random Matrix Theory: Applications and their Relation to Langevin Equation.*
11.10 – 11.30	**Coffee Break**

Session: Interdisciplinary Physics

Chairman: Martin Bier

11.30 – 12.00	**Gerhard Schmid** *Channel noise reduction due to gating charge effects*
12.00 – 12.45	**Aneta Stefanovska** *Cardio-respiratory synchronization transitions at high altitudes*
12.45 – 13.00	**Closing Remarks**
13.00 – 14.30	**Lunch**
15.00 – 20.00	**Excursion**

July 26th 2007 – departure day