FLUCTUATING ASYMMETRY: A POTENTIAL INDICATOR FOR ENVIRONMENTAL MONITORING IN THAILAND

Poranee Utayopas

Department of Biotechnology, Faculty of Science and Technology, Thammasat University, Rangsit Campus, Pathum Thani, 12121.

Abstract

Environments in Thailand have been badly threatened but few of the ecological consequences have been determined. Impact assessments have mostly concentrated on chemical analyses of pollutant residues in the environment. Biological data, however, are limited, with 2-3 approaches being used. In this paper, the advantages and limitations of monitoring approaches and the potential of fluctuating asymmetry as an indicator of environmental disturbances in Thailand are discussed.

1. Introduction: the situation of environments in Thailand

Environments in Thailand have been subjected to a range of anthropogenic disturbances for over twenty years. Such disturbances have caused widespread deterioration of the environments over various areas in Thailand. Extensive destruction of the habitats by illegally cutting down trees and deforestation for agriculture has reduced the Thai forest area from 273,628.5 km^2 or 53.33% of total area in 1961 to 136,698 km^2 or 26.64% of total area in 1992 [1]. Even though the ecological impact from such destruction can not be clearly determined because the ecosystem is complex, twelves animal species have been reported to be extinct with 129 animal and 100 plant species being endangered [2]. In addition, the severe erosion of soil recorded in Thailand in 1984 was as high as 5,020,021.60 hectares or 31.8% of the total area [3].

Mangrove forest, an important nursery and culture area for marine and shoreline products, has also been badly threatened by aquaculture ponds and charcoal production. The mangrove forest area in Thailand has decreased 46.6% over the past 15 years, from 367,900 hectares in 1961 to 19,642.24 hectares in 1986 [4,5].

A wide range of environmental impacts have been detected from mining in the sea and the shoreline along the lower western coast of Thailand. These include the reduction of species composition, density and biomass of marine benthic faunas, the destruction of coral reefs and mangrove forests and the erosion and collapse of shorelines [6].

The most significant impact detected over the past twenty years, perhaps, is the widespread contamination by pollutants in the environment. A remarkable increase in the number of factories (over 90,000 as estimated in 1985 [7]) and the heavy use of fertilizers and pesticides are the greatest sources of pollutants distributed in soil and water. These finally passed to various trophic levels through the food chains. Various kinds of pesticide residues have been widely detected in vegetables, fruits and food [8]. In addition, the concentrations of DDT detected in human milk, blood and fat in 1981 were 3.12, 0.5 and 14.29 ppm, respectively [8]. In the aquatic ecosystem, rivers running through industrial and agricultural areas are polluted with various kinds of toxicants, and finally discharge into the Gulf of Thailand. It was estimated that heavy metals and pesticides running into the Gulf of Thailand in 1985 were as high as 9,000 and 2,700 ton/year, respectively [9]. Bamrungrajhirun *et al.* [10] and Jarach [11] have also noted an increasing trend in the concentrations of heavy metals in the sea water and sediments sampled from the upper gulf and eastern coast of Thailand.

A remarkable decline in marine faunas caught in the Gulf of Thailand has also been observed. Such reduction was claimed to be the result of over exploitation and pollution [2,12].

Even though the severity of environmental problems in Thailand has been widely recognized by both the government and private agencies, few of these impact damages have been determined. Monitoring and assessment of the detrimental impacts, therefore, are urgently needed in Thailand. The use of sensitive indicators in monitoring programs is undoubtedly a great advantage. Rapid detection allows early remedial action to take place, consequently preventing serious or irreversible damage of the systems.

2. Monitoring approaches in Thailand

Chemical analysis is a popular method and most used in environmental monitoring in Thailand. In the aquatic ecosystem, environmental impacts reported by the government mainly were the pollutant residues in soils, water and various trophic levels in the ecosystems. A small number of impacts have been detected by biological monitoring, mainly the results of short term toxicity (LC_{50}) tests, biodiversity surveys and monitoring.

One of the reasons why chemical analysis is widely used is probably its simplicity and ease of interpretation. Ecological impacts of various pollutants, however, are often difficult to predict from a knowledge of instaneous concentrations. The toxicity of pollutants can be strongly influenced by various environmental factors and may vary between ecosystems [13]. Chemical analyses of water and sediments alone are not enough to provide quantitative information on the amount, history and ecological effects of pollutants. An organism responds to stress not only during the period in which it is exposed but continuously throughout its life [14]. Also it may show effects of concentrations below analytical detection l imits.Even when continuous monitoring of chemical and physical characteristics is conducted, such data alone are unreliable predictors of biological responses [15].

In addition, chemical residues in organisms may not correspond with the chemical analyses of the environments. For example, Millington and Walker [16] found that the concentration of zinc, iron and manganese in freshwater mussels *V. ambiguus* raised in cages in the metal polluted Molonglo River, New South Wales, Australia, did not accurately reflect the temporal fluctuation of concentrations of these metals in the river. Futhermore, the amounts of residues in different species in the same environment may differ depending on their rates of uptake and retention [17]. Substances may be quickly taken up and retained in some organisms, whilst in others they may be rapidly broken down and eliminated [18]. Moreover, the accumulation of residues in organisms may also depend on other chemical characteristics such as adsorption onto sediment particles [19] and synergistic or antagonistic relations with other chemical substances [20]. Different uptake rates may also be the result of other factors such as sex, transformation and season [20]. As a result, information both from chemical and biological data are essential for the determination of impacts.

Biological approaches, however, have their limitations. Toxicity tolerance tests carried out in the laboratory may not provide adequate assessment of an organism's response within the ecosystem because it lacks ecological complexity such as inter and intraspecific competition, predator-prey relationships,and energy exchange. Hence there is a high risk of drawing erroneous conclusions from the results of short term toxicity tests, which may lead to adequate or excessive environmental protection measures [18]

Even though biodiversity surveys and monitoring can detect changes both in species levels and community structures, this approach is time consuming and requires very high taxonomic efforts. The lack of skilled taxonomists in Thailand [21] is a crucial limitation of this approach. Experience of serious damage occurring over various areas has revealed that biodiversity monitoring may not be appropriate to all situations in the Thai environment. The time when damage is detected by this method may be too late for remedial action. In this case, other short term approaches are likely to be more advantageous.

3. Fluctuating asymmetry: another choice for monitoring programs in Thailand

Fluctuating asymmetry (FA) is a minor morphological deviation from normal symmetry. For paired bilateral characters, FA is non directional differences between left and right sides [22] which can be detected by examining the normal distribution of sign differences of left minus right around a mean of zero [23]. The assumption underlying this analysis is under normal conditions, the development in the two sides of bilateral characters is expected to be identical because they are controlled by the same genomes. Under stressful conditions, however, the buffering efficiency by homeostatic mechanisms is reduced, resulting in decreased levels of symmetry [24]. FA, therefore, can reflect the degree of stress imposed on developmental stability in individuals [25]. The biochemical and physiological processes underlying this mechanism are not fully understood but negative feed back control is thought to play a part in these processes [26,27].

A number of studies have recommended FA as a sensitive indicator for detecting environmental disturbances [23, 25, 28, 29, 30]. The major advantage of FA is its increased sensitivity over other approaches that rely on life parameters such as survival, fecundity, growth [25]. As a result, FA can detect low levels of changes before levels high enough to cause widespread morbidity or changes in community structure are reached. Evidence supporting this hypothesis is the study of Clarke and Ridsdill-Smith [31] on the dung breeding bush fly *Musca vetustissima*. Reduced survival and increased levels of FA were detected in flies bred in dung containing antiparasitic drug-Avermectin. However, flies exposed to Avermectin residues in dung 8 and 11 weeks after treatments, had increased levels of FA, indicating developmental stress by these residues, despite no response of survival being detected.

FA has been widely used as measure of developmental stability in the field of genetics and population biology. It was not until the early 1970s that FA was acknowledged as a potential indicator for detecting environmental disturbances in natural populations [25]. The relationships between FA and a number of environmental stressors have been revealed in various species. Increase in levels of FA of mandibular molar teeth of laboratory rats *Rattus norvegicus albinicus* was detected when the rats were prenatally and postnatally exposed to audiogenic stress [32, 33] and stresses from heat, cold, noise and protein deprivation [34]. Positive correlations between FA and stressors were also detected in bristle characters of *Drosophila melanogaster* and the sheep blow flie *Lucilla çuprina* exposed to lead and benzene concentrations [35] and stresses from crowding and temperature [36], respectively. In addition, increase in FA of stenopleural numbers were found in *D. melanogaster* raised at high temperature [37] and fluctuating temperatures [38]. Similarly, Pankakoski [39] found negative correlations between FA in numbers of foramina in the skull of muskrat *Ondatra zibethicus* and suitability of the habitats. In aquatic studies, positive correlations were detected between FA of meristic characters and pollutant levels in the barred sand bass *Paralabrax nebulifer*, the grunion *Leuresthes tenius* and the barred surperch *Amphistichus argenteus* [28, 29]. Ames *et al.* [40] have also reported the relationships between FA of meristic characters and mercury in the largemouth bass *Micropterus salmoides,* the bluegill. sunfish *Lepomis macrochirus* and the redbreast sunfish *Lepomis auritus*. In addition, Leary *et al* [41] demonstrated that the rainbow trout *Oncorhynchus mykiss* raised in warmer and cooler temperature displayed a higher average number of asymmetric characters per individual than those raised at normal temperature. High levels of FA of meristic characters were also detected in rainbow trout raised at high densities [41]. Levels of FA related to the El Niño-Southern-Oscillation event of 1982-1983 has been observed in the Pacific hake *Marluccius productus*. Alados *et al.* [42] found that FA of otolith weights and shape of the El Niño fish were higher than those sampled in other years. Similarly, Clarke [43] demonstrated that levels of FA of shrimp *Palaemon elegans* and bloodworm *Chironomous salinarius* collected from aquatic systems surrounding a chemical factory were significantly greater than in controls. Significant increase in FA of skull morphological characters of the grey-seal *Halichoerus grypus* in the Baltic sea after severe pollution with DDT and PCB in 1960 has also been observed by Zakharov and Yoblokov [44].

FA has also been recommended for detecting environmental stress in conservation biology [23, 30]. One theory suggested by Clarke [30] is a measure of developmental stability as an indirect estimate of the fitness of individuals in a population. Individuals with reduced fitness should reveal lower developmental stability, resulting in greater asymmetry than the fitter. In addition, changes in developmental stability may also predict subsequent changes in fitness. The assumption underlying this is changes in developmental stability will be manifest in the phenotype before changes in the more direct components of fitness such as fecundity will be detected.

The significant advantage of FA over other approaches, however, is this method is simple, cheap and needs only unskilled labour to carry out. These features are highly appropriate to the monitoring programs in Thailand, where financial and scientific skills are typically constrained. The measurement of FA is easily carried out and does not need highly sophisticated equipment. Only simple equipment such as vernier calipers or a microscope are needed for measurement of FA. In addition, FA can be applied to a wide range of organisms including plant and animal species in both natural and laboratory populations [25].

4. Limitations

FA is a relative estimated value for which there is no standard or reference value of asymmetry. Any conclusion in a given population is the result of comparison with control or reference populations [25].However, reference populations are becoming difficult to find because of increased habitat destruction and perturbation [30]. In addition, asymmetry responses are complicated and varied among locations due to genetic adaptation to differing habitats [45]. The sensitivity of various trends of stresses may not be the same in each location. As a result, comparison of the effects of the same stress from differing locations using FA may not be practical or valid. However, FA can be possibly used for detecting changes in populations over time. For example, FA examined before and after dam building may allow any pattern of temporal changes from such building to be detected quickly. This will allow rapid remedial actions, and consequently effective protection of the habitat.

The need for large sample size to prevent statistical robustness is the other limitation of FA. In some cases such as the studies of FA in endangered or threatened species, large sample sizes may not be available and the measure of FA may not be applicable. However, Clarke [30] argued that when the reduction of populations occurred through decreased fecundity or survival, sensitive indicators such as FA may not be needed because the effects of stress have already been shown.

The choice of species is also an important factor for measure of FA. Sensitive species seem to disappear from the disturbed habitats quickly. It is regretful that collection of samples before an impact occurs is rarely obtained because biomonitoring and conservation programs typically commence too late [30]. Skeleton or preserved specimens in museums may be good sources, however, large sample sizes may not be available. In addition, impacts detected by FA in high tolerance species may provide inadequate sensitivity. For example, the Swan River goby *Pseudogobius olorum* collected from Perth wetlands, appeared to be a more sensitive indicator than the mosquito fish *Gambusia holbrooki* collected from the same locations. This is revealed by the significant higher levels of FA of meristic characters in *P. olorum* than those of *G. holbrooki*. However, the distribution of *P. olorum* in Perth wetlands is limited, partly it is believed to be a result of low tolerance to stress in this species [45]. On the other hand, *G. holbrooki*, a famous species for high stress tolerance and found widely distributed around the world, seems not to be a good species indicator because its FA is insensitive. Evidence supporting this is the lack of significant difference detected in levels of FA in *G. holbrooki* collected from low polluted wetlands in Perth and *G. affinis* collected from heavily polluted water bodies in Thailand [45].

5. Conclusions

The fact that FA is simple, cheap and needs only unskilled labour to carry out may allow this method to be a potential tool for monitoring programs in Thailand. The sensitivity of FA also fulfills the requirement of an early warning indicator for detecting detrimental effects in the Thai environment. However, all monitoring approaches have their limitations. As a result, the use of integrated programs, in which impacts are monitored by various approaches, probably has a greater advantage over long term monitoring. FA may be useful as an initial stage of the investigation. The assessments following by a number of methods will allow all aspects of ecosystem to be detected. This will lead to effective protection of the ecosystem.

6. References

[1] Charuppat, T. 1992. Analysis of forest situation of Thailand from LANDSAT imagery (in Thai). Measurement and Map Office. Royal Forestry Department, Bangkok, Thailand.

[2] National Biodiversity Unit. 1992. Thailand country study on biodiversity (main volume). Office of Environmental Policy and Planning. Ministry of Science, Technology and Energy, Bangkok, Thailand.

[3] Department of Land Development. 1984. Annual report 1984 (in Thai).

[4] Klunkumsorn, B. and Charuppat, T. 1982. Reports of the results from classifications of the land uses in mangrove forest areas in Thailand (in Thai). Remote Sensing Sub-Division, Forest Management Division. Royal Forestry Department, Bankok,Thailand.

[5] Klunkumsorn, B. and Charuppat, T. 1987. The study of changes in mangrove forest areas in Thailand using LANDSAT imagery (in Thai). Forest Management Division, Royal Forestry Department, Bangkok, Thailand.

[6] Office of National Environment. 1983-1984. Reports of environmental quality in Thailand during 1983-1984 (in Thai). Ministry of Science, Technology and Energy, Bangkok Thailand.

[7] Office of National Environment. 1985. Reports of environmental quality in Thailand in 1985 (in Thai). Ministry of Science, Technology and Energy. Bangkok. Thailand.

[8] Office of National Environment. 1981-1982. Reports of environmental quality in Thailand during 1981-1982 (in Thai). Ministry of Science, Technology and Energy, Bangkok Thailand.

[9] Santatiwut, N. 1985. River Pollution and the quality of living resources (in Thai). The proceeding of the living aquatic resources at Chulalongkorn University 7-8 March 1985.

[10] Bamrungrajhirun, R. Charach, W. and Chingchit, K. 1987. Heavy metal contents in sea water and sediments of the upper Gulf and the eastern coast of Thailand during 1983-1986 (in Thai). Proceeding of the forth siminar on the water quality and the quality of living resources in Thai waters, 7-9 July 1987, Surat Thani, Thailand.

[11] Jarach, W. 1987. Heavy metal contents in sea water of the upper Gulf of Thailand (in Thai).Proceeding of the forth siminar on the water quality and the quality of living resources in Thai waters. 7-9 July 1987, Surat Thani, Thailand.

[12] Office of National Environment. 1980. Reports of environmental quality in Thailand in 1980 (in Thai). Ministry of Science, Technology and Energy, Bangkok, Thailand.

[13] Viswanathan, P. N., Jaffery, F. N., Misra,V. and Chawla, G. 1988. Biomonitoring and freshwater ecotoxicology: an over view. In de Kruijf, H. A. M., de Zwarf, D., Viswanathan, P. N. and Ray, P. k. Manual on aquatic ecotoxicology. Allied, India.

[14] Cairns, J. Jr 1975. Critical species, including man within the biosphere. Naturwissenschaften62: 193-199.

[15] Cairns, J. Jr 1981. Biological monitoring Part VI - Future needs. Water Research 15: 941-952.

[16] Millington, P. J. and Walker, K. F. 1983. Australian freshwater mussel *Velesunio ambiguus* (Phillippi) as a biological monitor of zinc, iron and manganese. Australian Journal of Marine and Freshwater Research 34: 873-892.

[17] Maher, W. A. and Norris, R. H. 1989. Water quality assessment programs in Australia deciding what to measure, and how and where to use bioindicators.Environmental Monitoring and Assessment 14: 115-130.

[18] Phillips, D. J. H. and Segar, D. A. 1986.Use of bio-indicators in monitoring conservative

contaminants: Program design imperatives. Marine Pollution Bulletin 17: 10-17.
[19] Prosi, F. 1983. Heavy metals in aquatic organisms, pp. 271-318. In Forstner, U. and Wittmann, G. T. W. Metal pollution in the aquatic environment. Springer-Verlag, Berlin.
[20] Phillips, D. J. H. 1980. Quantitative aquatic biological indicators. Applied Science, London.
[21] Brokleman, W. Y. 1995. What exactly is biodiversity survey and monitoring? (inThai). Science (Thailand) 49(6): 362-366.
[22] Van Valen, L. 1962. A study of fluctuating asymmetry. Evolution 16: 125-42.
[23].Leary, R. F. and Allendorf, F. W. 1989. Fluctuating asymmetry as an indicator of stress: implications for conservation biology. TREE 4 (7): 214-24.
[24]Clarke, G. M., Brand, G. W. and Whitten,M. J. 1986. Fluctuating asymmetry: a technique for measuring developmental stress caused by inbreeding. Australian Journal of Biolological Sciences. 39: 145-53.
[25] Clarke, G. M.1994 Developmental stability analysis: an early-warning system for biological monitoring of water quality. Australian Biologist (2): 94-102.
[26] Lerner, I. M. 1954. Genetic homeostasis. Wiley, New York.
[27] Zakharov, V. M. 1981. Fluctuating asymmetry as an index of developmental homeostasis. Genetika 13: 241-256.
[28] Valentine, D. W. and Soulé, M. 1973. Effects of *p, p'*-DDT on developmental stability of pectoral fin rays in the grunion *Leuresthes tenuis*. Fishery Bulletin 71(4): 921-26.
[29] Valentine, D. W., Soulé, M. E. and Samollow, P. 1973. Asymmetry analysis in fishes: a possible statistical indicator of environmental stress. Fishery Bulletin 71: 357-70.
[30] Clarke, G. M. 1995. Relationships between developmental stability and fitness: Application for conservation biology. Conservation Biology 9(1): 18-24
[31] Clarke,G.M.and Ridsdill-Smith, T. J. 1990. The effect of Avermectin B_1 on developmental stability in the bush fly,*Musca vetustissima*, as measured by fluctuating asymmetry. Entomologia Experimentalis et applicata 54: 265-9.
[32] Siegel, M. I. and Doyle, W. J. 1975. The differential effects of prenatal and postnatal audiogenic stress on fluctuating asymmetry. Journal of Experimental Zoology 191: 211-214.
[33] Siegel, M. I. and Smookler, H. H. 1973. Fluctuating dental asymmetry and audiogenic stress. Growth 37: 35-39.
[34] Sciulli, P. W., Doyle, W. J., Kelley, C., Siegel, P. and Siegel, M. I. 1979. The interaction of stressors in the induction of increased levels of fluctuating asymmetry in the laboratory rat. American Journal of Physical Anthropology 50: 279-284.
[35] Graham, J. H., Freeman, D. C. and Emlen, J.M.1993.Developmentalstability: A sensitive indicator of populations under stress, pp.136-158. In Landis, W. G., Hughes, J. S. and Lewis, M. A. Environmental Toxicology and Risk Aassessment, ASTMSTP 1179. American Society for Testing and Materials, Philadelphia.
[36] Clarke, G. M. and Mckenzie, J. A. 1987. Developmental stability of insecticide resistant phenotypes in blowfly: a result of canalizing natural selection Nature. 325: 345-346.
[37] Parsons, P. A. 1990.Fluctuating asymmetry: an epigenetic measure of stress. Biological Reviews 65: 131-145.
[38]Bradley, B. P. 1980. Developmental stability of *Drosophila melanogaster* under artificial and natural selection in constant and fluctuating environments. Genetics 95: 1033-1043.
[39] Pankakoski, E. 1985. Epigenetic asymmetry as an ecological indicator in muskrats. Journal of Mammalogy 66: 52-57.
[40] Ames, L. J., Felley, J. D. and Smith, M. H. 1979. Amounts of asymmetry in centrarchid fish inhabiting heated and nonheated reservoirs. Transactions ot the American Fisheries Society 108: 489-495.
[41] Leary, R. F., Allendorf, F. W. and Knudsen, K. L. 1991. Effects of rearing density on meristics and developmental stability of rainbow trout. Copeia: 44-49.
[42] Alados, C. L., Escos, J. and Emlen, J. M. 1993. Developmental instability as an indicator of environmental stress in the Paciffic hake (*Merluccius productus*). Fishery Bulletin 91: 587-593.
[43] Clarke, G. M. 1993. Fluctuating asymmetry of invertebrate populations as a biological indicator of environmental quality. Environmental Pollution 82: 207-211.

[44] Zakharov, V. M. and Yoblokov, A. V. 1990. Skull asymmetry in the Baltic grey seal: effects of environmental pollution. Ambio. 19 (5): 266-269.

[45] Utayopas, P. 1995. Fluctuating asymmetry of fish populations as a bioindicator of environmental quality in aquatic ecosystems. Ph. D. Thesis, Murdoch University, Western Australia.