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Modern Zoology as a “Classical” Branch of Biology has Developed to Play an Integrative Role with a Focus on the Whole Organism

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Abstract

The concept of zoology as a single coherent field arose over the 18th and 19th century. It has been influenced by the systems theory and advances in the modern molecular biological methodology. As a consequence, zoology split into many specialized fields and “organisms” were more and more replaced by “systems”. This study intends to identify conceptual changes in zoological research publications by data mining the bibliographic entries of the online database PubMed for topic-specific keywords that may reveal changes in the ratio of molecular and whole organism level in zoology publications (1918-2017). For this, major and minor topics of the publications were counted with the data mining tool RefViz (Thomson Research). The top 64 of these lists were distinguished to be on the molecular or on the whole organism level. The results indicate an increase in whole organism based zoological publications while those on the molecular level were decreasing.

Keywords

Zoology; Natural history; Ecosystem

Abbreviations: 5-ht: 5-Hydroxytryptamine; Ache: Acetylcholinesterase; Ae: Aedes (Mosquito); Ag: Silver; Gnps: Silver Nano Particles; Ar: Androgen Receptor; Ca^{2+}: Calcium; Cd: Cadmium; DNA; Deoxyribonucleic Acid; e^2: Estradiol; Gaba: Gamma Amino Butyric Acide; Gh: Growth Hormone; Gnrh: Gonadotropin-Releasing-Hormone; Gth: Gonadotropin; Hiv-1: Human Immunideficiency Virus; Hsp70: Heat Shock Protein 70; Igf-i: Insulin-like Growth Factor; Lh: Luteinizing Hormone; Mhc: Major Histocompatibility Complex; Mirnas: Micro RNAs; Nh3: Ammonia; Nps: Nano Particles; Ni: Nickel; P53: Protein P53; Pd: Parkinsons Disease; Pkc: Protein Kinase C; Prl: Prolactin; T3: Triiodo-L-Thyronine; T4: L-Thyroxine

Introduction

The conceptual change of zoology as a science

The term zoology in this study means the branch of biology that studies the animal kingdom, including the structure, embryology, evolution, classification, habits, and distribution of all animals and their interaction with the biotic and abiotic environment.

Zoology as a science and “classical” field of biology has a long history of more than 2000 years. The history of zoology traces the study of the animal kingdom from ancient to modern times. Zoological sciences emerged from natural history reaching back to the works of Aristotle and Galen in the ancient Greco-Roman world. The concept of zoology as a single coherent field arose much later over the 18th and 19th century [1,2] and is one of the natural sciences attracting most public attention [3]. In contrast to this, zoology as a scientific field occasionally is considered to be old-fashioned [4]. Reason for this was emerging of more specialized zoology related sub-disciplines as a result of focusing on selected aspects of animal biology. As a consequence, zoology as a science was more and more replaced by a number of autonomous research areas, focusing different levels of the “system life”: molecules, cells, tissues, regulation and adaptation, model animals or whole ecosystems. Someone may ask for a strategy for how to keep these fragmented topics together. A look into the history of sciences reveals the answer.

It was in the 1940’s when the idea came up to counteract these dynamics by defining systems principles that keep science together-systems theory was born. This minorize was proposed by the biologist Ludwig von Bertalanffy, and furthered by Ross Ashby [5,6]. Although those ideas and concepts were quite technical and catalyzed the loss of the term “organism” by more and more replacing it by “system” [7]. Nevertheless, the basic ideas were attempts to revive the unity of science and reacting against reductionism. Von Bertalanffy emphasized that real systems are open to, and interact with, their environments. Furthermore, they can gain qualitatively new emergent features, resulting in continual evolution.

In the time system theory came up another topic led to disruptive changes. Molecular biology was established in the 1930’s [8] and was always an interdisciplinary field (chemistry, biochemistry, and genetics). Advances in the modern molecular biological methodology rapidly enabled researchers in “classical” fields of biology, like zoology and botany, to develop the hypothesis for their observations that have the power to explain phenomena and emergent systems properties on different levels of organization. But can we explain life on a whole organism level with molecular biology alone? Astbury described molecular biology as: “...not so much a technique as an approach, an approach from the viewpoint of the so-called basic sciences with the leading idea of searching below the large-scale manifestations of classical biology for the corresponding molecular plan. It is concerned particularly with the forms of biological molecules and [...] is predominantly three-dimensional and structural-which does not mean, however, that it is merely a refinement of morphology. It must at the same time inquire into genesis and function.” [9]. Without doubts, molecular methods added a high value to many aspects of classical fields of biology. Today, researchers are always asked to explain the underlying mechanisms and in most cases, they end up in molecular biological experiments.

But, researchers, especially those with their roots in classic zoology, should always keep in mind the question “What does this mean to the whole animal?”. There is still a need for researchers with a holistic view of the results of modern life sciences. Jörg Albrecht, a German science journalist, and biologist asked the question if there is a future for classical zoology and botany. In his article, he came to the

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answer "Specialists like to divide the flora and fauna into ever smaller portions, here a cell, there a carbon compound, here an atom, there a neutrino, to the end everything consists of quarks. The secret of life cannot be deciphered on that level, because an animal, a plant, a bacterium, even a virus is always very much more than the sum of its parts. This is why: generalists, desperately sought" [10]. Is it true that zoology is outcompeted by other disciplines? And is it true that analysis on the whole organism level is losing importance?

Re-evolution of the concept of zoology

In the last decade, a process started to evolve the former "old fashioned" zoology into a modern zoology, which serves as an integrative discipline encompassing all aspects of animal life, from the level of the gene to the level of the ecosystem.

The current challenge of the modern zoology is the re-integration of zoological disciplines and simultaneously taking advantage of a broader approach to the holistic study of animal life. This is reflected by the increasing number of new zoology journals, like Zoo Keys, Frontiers in Zoology, International Journal of Zoology, Archives of Zoological Studies and Research Journal of Zoology (the journal, you are reading right now). How did the semantic content of zoology publications change when focusing on the question if molecular biology still displaces the concept of the organism?

In the following, some superficial analysis of the major zoological research topics using the bibliographic information in the database PubMed with the search term "zoology" in title and abstract fields is presented. From 67.475 hits 5404 were excluded (incomplete database entries, like missing titles) and the remaining 62.071 were imported in RefViz 2 (Thompson Reuters, New York). RefViz is data mining software for reference databases like PubMed. It provides a similarity-based clustering by statistical analysis of the vocabulary in the Titles and Abstracts of the reference set and how the terms in that vocabulary were categorized during processing. Major Topics are the terms that best distinguish sets of references - they are the most important concepts. Minor topics are less distinguishing, but have some influence on the grouping of references through their co-occurrence with the major topics. Words that are too frequent or too infrequent to help define groups of references, or they are not distributed in a manner that would help distinguish groups are excluded. PubMed® uses the MeSH index to find references with related concepts; thus, the query "zoology" itself may not necessarily appear in the reference itself.

For the current study, three subsets of publication year periods 1918-1999, 2000-2011 and 2012-2017 were analyzed for their most dominant (distinguishing) and minor (less distinguishing) topics. The results are shown in Table 1 (sorted by number of term occurrence) and Table 2 (alphabetically sorted). Table 3 shows the number of terms indicating the whole organismic level compared to the molecular level. The whole organismic level terms show an increase by 41% in contrast to terms indicating the molecular level, which decreased by more than 50 % both when comparing publications of the past 5 years

Table 1: Text analysis of the top 64 major zoological research topics using the bibliographic information in the database PubMed with the search term "zoology" in title and abstract. From 67.475 hits 5404 were excluded (incomplete database entries, like missing titles). The periods 1918-1999, 2000-2011 and 2012-2017 were analyzed for their most dominant (distinguishing) and minor (less distinguishing) topics in order of term occurrence. Terms in italics indicates topics on the molecular level. Terms in bold indicates topics on the whole organism level. n=16222 (1918 - 1999), 22222 (2000 - 2011) and 23627 (2012 - 2017) respectively.

1918 - 1999				**2000 - 2011**				**2012 - 2017**			
Major Topic	**# of papers**	**Minor Topic**	**# of papers**	**Major Topic**	**# of papers**	**Minor Topic**	**# of papers**	**Major Topic**	**# of papers**	**Minor Topic**	**# of papers**
neuron	1065	cell	2947	sperm	509	**species**	2424	**rat**	1243	**species**	3489
fiber	667	activity	1973	oocyte	498	cell	2163	**mosquito**	613	activity	2219
ca2+	606	**species**	1751	*ca2+*	275	activity	1834	malaria	498	cell	2152
oocyte	451	*protein*	1546	*zinc*	250	*protein*	1683	**Aedes aegyptii**	384	*gene*	1873
sperm	445	*concentration*	1442	**bat**	220	male	1295	sperm	371	*protein*	1687
virus	329	body	1251	**ant**	205	*gene*	1287	oocyte	309	population	1674
wing	266	rate	1248	**tick**	202	rate	1258	**bat**	268	*expression*	1574
prolactin	216	male	1237	**spider**	195	concentration	1256	**snail**	246	male	1442
flight	207	female	1218	*melatonin*	184	*expression*	1246	**tick**	245	concentration	1314
seed	203	population	1076	**bat**	162	population	1157	**ant**	235	female	1291
tick	199	blood	987	**mite**	155	female	1153	**bee**	234	evolution	1109
microtubule	191	*hormone*	920	*pheromone*	145	evolution	918	diabetic	200	*genetic*	1079
goldfish	177	**rat**	919	**locust**	144	*sequence*	881	**dog**	192	exposure	1050
lh	169	tissue	902	song	140	exposure	866	part per million	182	infection	1044
corticosterone	167	site	883	hypoxia	139	behavior	840	hypoxia	165	signal	935
gnrh	160	*receptor*	864	**shrimp**	137	*receptor*	826	venom	141	host	929
bat	155	*gene*	842	spindle	135	**fish**	811	*pheromone*	136	**mouse**	915
t3	153	growth	839	*vitamin*	127	**mouse**	795	song	135	behavior	895
snake	151	*release*	835	**dog**	124	signal	784	placenta	134	size	866
insulin	145	behavior	821	**tadpole**	123	size	756	**aphid**	132	blood	813
melatonin	138	size	811	**earthworm**	122	growth	731	influenza	131	extract	786
gaba	131	muscle	811	venom	120	reproductive	707	*ca2+*	129	dose	760
turtle	129	*expression*	776	*cortisol*	120	water	696	nps	125	water	733
deer	127	membrane	764	**vole**	118	**rat**	695	*melatonin*	123	risk	728
hair	125	model	756	**aphid**	111	*genetic*	675	wound	120	*receptor*	726

vole	123	**mouse**	714	fin	110	host	596	**honeybee**	115	growth	723
t4	122	plasma	689	**seal**	109	*hormone*	596	**earthworm**	112	vector	721
odor	121	brain	673	**mussel**	104	feed	595	feather	109	plant	715
interneuron	119	**fish**	671	*e2*	95	dose	563	*ni*	108	*dna*	711
cortisol	119	production	669	*aromatase*	94	*dna*	538	honey	104	**insect**	709
cadmium	119	*sequence*	665	**deer**	93	temperature	536	**turtle**	101	reproductive	707
pineal	115	**human**	650	diabetic	81	mass	529	*mirnas*	101	genus	694
Flower	110	culture	623	*gh*	77	**insect**	522	**deer**	95	parasite	688
ant	110	bind	601	pineal	76	muscle	502	**sponge**	93	feed	674
spider	108	feed	594	*mhc*	76	blood	497	**shrew**	93	liver	658
gh	107	reproductive	580	imprint	74	release	494	**locust**	92	toxicity	624
squirrel	100	cycle	580	torpor	74	egg	491	**shark**	90	anti-oxidant	621
mite	99	temperature	561	*nh3*	74	intection	486	**mussel**	88	age	608
gth	96	**insect**	540	*mercury*	74	liver	480	**horse**	88	**fish**	606
bee	96	evolution	530	**horse**	74	plasma	474	pd	84	serum	593
e2	94	dose	530	**goldtish**	74	food	466	*mhc*	83	oxidative stress	585
venom	90	phase	524	*gnrh*	74	brain	466	autophagy	82	compound	581
song	88	*enzyme*	519	*arsenic*	72	phase	461	*agnps*	82	brain	577
motoneuron	87	*antibody*	519	**squirrel**	71	culture	454	schizophrenia	81	**larva**	562
lectin	84	*nucleus*	514	**shark**	71	age	454	*ag*	81	selection	514
ethanol	84	signal	510	jump	69	sex	453	biofilm	80	mitochondrial	513
pkc	83	acid	510	sleep	68	**bird**	452	pollen	79	food	511
fish	81	light	504	*ar*	68	plant	437	*curcumin*	79	drug	504
shrimp	78	egg	501	silk	67	selection	436	jump	78	temperature	502
cd	76	nerve	492	*leptin*	67	*mrna*	427	hiv-1	78	habitat	499
seal	75	embryo	484	hiv-1	67	bind	416	*arsenic*	77	pathogen	498
mhc	74	secretion	481	queen	65	extract	409	sensillum	76	wild	492
caffeine	72	**drosophila**	465	maize	64	**embryo**	409	**vole**	74	virus	483
imprint	69	larva	449	cotton	64	larva	407	gastric	71	resistance	478
duck	68	medium	448	*methylation*	63	degrees c	403	**salmon**	70	**bird**	469
pollen	65	*genetic*	447	*p53*	62	disease	402	**goat**	70	acid	465
aromatase	65	host	443	**crayfish**	62	gland	395	rice	69	strain	461
5-ht	65	*dna*	443	notochord	60	nucleus	389	**whale**	68	prevalence	457
mercury	64	density	439	lens	59	density	389	**scorpion**	68	density	453
wheel	62	**bird**	439	*hsp70*	59	metabolic	387	**lion**	66	trait	452
sensillum	61	water	437	**eel**	58	stress	384	**hamster**	67	*genome*	452
interferon-gamma	61	degrees c	435	*igf-i*	57	energy	373	**buffalo**	64	egg	450
ache	61	sex	433	diapause	57	breed	373	silk	61	patient	447
histone	60	liver	431	pollen	56	sexual	368	*nh3*	61	stress	441

Table 2: Text analysis of the top 64 major zoological research topics using the bibliographic information in the database PubMed with the search term "zoology" in title and abstract. From 67.475 hits 5404 were excluded (incomplete database entries, like missing titles). The periods 1918 – 1999, 2000 – 2011 and 2012 – 2017 were analyzed for their most dominant (distinguishing) and minor (less distinguishing) topics in alphabetical order of terms. Terms in italics indicates topics on the molecular level. Terms in bold indicates topics on the whole organism level. n=16222 (1918 - 1999), 22222 (2000 - 2011) and 23627 (2012 - 2017) respectively.

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ache	61	activity	1973	**aphid**	111	age	454	*ag*	81	activity	2219
ant	110	*antibody*	519	*ar*	68	behavior	840	*agnps*	82	age	608
aromatase	65	behavior	821	*aromatase*	94	bind	416	**ant**	235	anti-oxidant	621
bat	155	bind	601	*arsenic*	72	**bird**	452	**aphid**	132	behavior	895
bee	96	**bird**	439	**bat**	220	blood	497	*arsenic*	77	**bird**	469
ca2+	606	blood	987	**bat**	162	brain	466	autophagy	82	blood	813
cadmium	119	body	1251	*ca2+*	275	breed	373	**bat**	268	brain	577

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caffeine	72	brain	673	*cortisol*	120	cell	2163	**bee**	234	cell	2152
cd	76	cell	2947	cotton	64	concentration	1256	biofilm	80	compound	581
corticosterone	167	*concentration*	1442	**crayfish**	62	culture	454	**buffalo**	64	concentration	1314
cortisol	119	culture	623	**deer**	93	degrees c	403	*ca2+*	129	density	453
deer	127	cycle	580	diabetic	81	density	389	*curcumin*	79	*dna*	711
duck	68	degrees c	435	diapause	57	disease	402	**deer**	95	dose	760
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pollen	65	phase	524	pineal	76	phase	461	pollen	79	prevalence	457
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sensillum	61	*protein*	1546	**shark**	71	*protein*	1683	schizophrenia	81	resistance	478
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tick	199	signal	510	**tadpole**	123	sexual	368	**sponge**	93	temperature	502
turtle	129	site	883	**tick**	202	signal	784	**tick**	245	toxicity	624
venom	90	size	811	torpor	74	size	756	**turtle**	101	trait	452
virus	329	**species**	1751	venom	120	**species**	2424	venom	141	vector	721
vole	123	temperature	561	*vitamin*	127	stress	384	**vole**	74	virus	483
wheel	62	tissue	902	**vole**	118	temperature	536	**whale**	68	water	733
wing	266	water	437	*zinc*	250	water	696	wound	120	wild	492

Table 3: Text analysis of the top 64 major zoological research topics using the bibliographic information in the database PubMed with the search term "zoology" in title and abstract. From 67.475 hits 5404 were excluded (incomplete database entries, like missing titles). The periods 1918-1999, 2000-2011 and 2012-2017 were analyzed for terms indicating molecular or organism level. n=64.

# of terms	1918-1999	2000-2011	2012-2017
Whole Organism level	24	28	34
Molecular level	40	29	18

to the period of 1918-1999. Although these numbers only represent a superficial analysis, they show the trend that the whole organism level in zoology publications can expect a renaissance. A reason for this may be the fact, that the number of animal models increases (bat, snail, ant, turtle, hamster, earthworm) as well as the number of important animals transferring human diseases (e.g. mosquito) or being of agri-and aquaculture interests (bee, honeybee, salmon/fish, locust, deer, goat, buffalo) are increasing. The Kroghs Principle (in modern language) "Among the diversity of animal species there will be one ideally suited as an experimental model for any biological problem" [11,12] is still and even more true in the modern world of science.

Conclusion

Zoology as a science has a future. Modern zoology has an important integrative role with a focus on the organism level and a holistic understanding of structures and functions. Besides the molecular level model animals have to be characterized on the whole organism level as well and the question that always has to be kept in mind is "What does it mean to the (whole) animal?"

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