Mutation Research 753 (2013) 1–6

Contents lists available at SciVerse ScienceDirect

Mutation Research/Reviews in Mutation Research

journal homepage: www.elsevier.com/locate/reviewsmr
Community address: www.elsevier.com/locate/mutres

Reflections in Mutation Research

How fruit flies came to launch the chromosome theory of heredity☆

Elof Axel Carlson [a,b,*]

[a] Department of Biochemistry (Emeritus), Stony Brook University, NY, United States
[b] Institute for Advanced Study, Indiana University, Bloomington, IN, United States

ARTICLE INFO

Article history:
Accepted 26 March 2013
Available online 11 April 2013

Keywords:
T.H. Morgan
Fernandus Payne
Fly lab
Blind cave fish
Experimental evolution
Origin of classical genetics

ABSTRACT

Fruit flies were used by several laboratories between 1901 and 1910 for studies of experimental evolution at Harvard, Indiana University, and Cold Spring Harbor before Thomas Hunt Morgan found his white-eyed mutation that we associate with the beginnings of the fly lab at Columbia University. The major players prior to Morgan were William Castle and his students at Harvard University, Frank Lutz at Cold Spring Harbor, and Fernandus Payne whose ideas for working with fruit flies were shaped by his studies of blind cave fauna at Indiana University. Payne's interests were stimulated by the work of Carl Eigenmann, an authority on blind cave fauna, and William Moenkhaus, who introduced Payne to fruit flies at Indiana University before Payne moved to Columbia to pursue graduate work with Morgan and Edmund Wilson. The motivations of the laboratories differed in the theories used for their work. Castle spread the word about the utility of fruit flies for research, but Payne gave Morgan his first fruit flies for research leading to the discovery of the white-eye mutation.

1. What genetics implied in 1906

The field of genetics got its name introduced to the public in 1906 when William Bateson renamed the Royal Society of Horticulture meetings of the *Third International Conference of Hybridisation and Plant Breeding* and called it the *Third International Conference of Genetics*. The name change reflected the rediscovery of Mendelism in 1900, making breeding analysis by experimentation a hallmark of the new field of genetics. In the first decade of the twentieth century, 1901–1910, several competing approaches claimed that their outlooks or findings were central to understanding the problem of heredity. Among these were those who saw Darwinian fluctuations as the raw material for natural selection and thus the effort of field biologists should be a search for these in appropriate species coupled with environmental studies in producing or selecting these fluctuations. The chief advocate of this was the British school of biometricians led by Karl Pearson and his colleagues. A second faction of biologists saw heredity as plastic in response to the environment and attributed that observed variation to direct modification by the environment. This view dated back to Lamarck's theory of the inheritance of acquired characteristics. A third faction, led by William Bateson in England and Hugo de Vries in Holland, believed heredity involved discontinuous events. Bateson had published a volume in 1894, *Materials for the Study of Variation, Treated with Regard to Discontinuity in the Origin of Species*, marshaling evidence of hundreds of newly arising variations that arose suddenly. Bateson claimed these had a role in the formation of new organ systems and embryonic body plans. The work of de Vries, *The Mutation Theory* (1901–1903), favored the origin of species by discontinuous sudden origins, and his experimental work used the evening primrose, *Oenothera lamarckiana*, as the source of these new species in his garden. A fourth faction, primarily American, used microscopy, and its leader was Edmund Beecher Wilson at Columbia University. He and his students and his colleague Theodor Boveri in Germany worked out in 1901–1903 what they called the chromosome theory of heredity and brought together the fields of breeding analysis and cytology by showing how meiotic events could determine Mendelian outcomes [1].

None of these groups dominated the new field of genetics by 1915. Instead, an outsider group headed by Thomas Hunt Morgan, with his students at Columbia University, established the major features of what we call classical genetics and for which Morgan received a Nobel Prize in 1933. Morgan achieved this through his experiments using fruit flies. The purpose of this article is to examine how and why Morgan decided to use fruit flies and how fruit flies came to launch classical genetics when their earlier use suggests quite different reasons for their experimental study in relation to heredity and evolution.

☆ This article is part of the Reflections in Mutation Research series. To suggest topics and authors for Reflections, readers should contact the series editor, G.R. Hoffmann (ghoffmann@holycross.edu).

* Correspondence address: PO Box 8638, Bloomington, IN 47407-8638, United States.
E-mail address: ecarlson31@netzero.com

1383-5742/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.mrrev.2013.03.001

2. Early studies with Drosophila begin at Harvard

The genetic route to Columbia University and Thomas Hunt Morgan's laboratory comes from three sources—Harvard, Indiana University, and Cold Spring Harbor. The motivations leading to the adoption of fruit flies for genetic research come from the influence of Carl Eigenmann (1863–1923), Hugo de Vries (1848–1935), Charles Davenport (1866–1944), and Edmund Beecher Wilson (1856–1939).

The use of fruit flies in biological research preceded Morgan's discovery of the white-eyed mutation by five to ten years. The principal investigators using fruit flies in those years included Charles Woodworth (1865–1940) and William Castle (1867–1962) at Harvard, as well as Castle's students, F.W. Carpenter, A.H. Clark, S.O. Mast, and W.W. Barrows, all at Harvard [2]. Castle explored fruit flies for studies of what was then called "experimental evolution". The term was coined by Charles Davenport, Castle's colleague at Harvard [3]. Castle got his Ph.D. in 1895 with Edward Laurens Mark (1847–1946), studying the tunicate *Ciona intestinalis* and demonstrating self-sterility in this hermaphrodite's gametes. Castle began his fruit fly studies in 1901 after Woodworth recommended the flies as easy to maintain and suitable for studies of experimental evolution. It was Castle's first publications on fruit flies that led to an interest in several laboratories on the value of fruit flies for evolutionary and genetic studies [4]. Woodworth was an entomologist who spent most of his career in California (at UC Berkeley) and happened to visit Harvard in 1900–1901. He was the first to cultivate fruit flies in large numbers and realize their benefit for experimental studies. It was the rediscovery of Mendelism that also excited Castle, and he ran parallel studies on mice and other mammals while doing his fly studies. The fly studies stressed the Darwinian tradition of looking at traits that varied quantitatively such as fertility (later more precisely described as fecundity) and viability (measured by number of offspring per pair of parents). He and his students subjected fruit flies to 60 generations of brother and sister inbreeding, and their offspring showed no diminution of vigor or fertility [5].

The aims of experimental evolution in the 1890s under Davenport's leadership at Harvard (and at the University of Chicago) included numerous tests of environmental influences on traits. These included physiological factors like pH changes, exposure to ether, agitation in mechanical shakers, or shifts in temperature. Davenport published a two-volume work on these studies, *Experimental Morphology*, in 1897–1899 [6]. This type of experimental Darwinism was widely studied in Great Britain and continental Europe. It supplemented field studies that the biometric school of Francis Galton, W.F.R. Weldon, and Karl Pearson stressed at Cambridge. It also was highly statistical in its presentation of means and extremes of variation [7]. Castle dropped the fruit fly studies after his publication of 1906 in favor of Mendelian studies on small mammals which turned out to be more rewarding in their analysis of coat color. Carpenter published only one fruit fly experimental evolution paper in 1905 [8]. Barrows published one paper on fruit flies in 1907 [9]. All of Castle's coauthors for the fly work went into other fields of biology. By 1908 Castle was in charge of genetics at Harvard, Davenport was in charge of genetics at Cold Spring Harbor but was now working on Mendelism in poultry, and the interest in fruit flies had shifted mainly to Indiana.

3. Carl Eigenmann uses cave fauna to study evolution

The Indiana route to Morgan did not come from the type of experimental evolution that Davenport and the British Darwinists favored. It came from studies of blind cave fish and other blind and albino animals. The first to take an interest in this at Indiana University was Carl Eigenmann (1863–1923). He was German-born, in Flehingen near Karlsruhe, but he was raised since age 14 in Rockport, Indiana. He got his education at Indiana University, receiving his Ph.D. under the mentorship of David Starr Jordan (1851–1931), an ichthyologist, evolutionist, popularizer of science, President of Indiana University and first president of Stanford University [10]. Through Jordan's influence, Eigenmann chose ichthyology and began exploring North American fresh water fishes. While Eigenmann was visiting San Diego, California, Jordan introduced Eigenmann to his future wife, Rosa Smith (1858–1947), also an ichthyologist, and she introduced Eigenmann to blind cave fish which she studied at Point Loma in San Diego [11] (Fig. 1). Jordan had taught Eigenmann the role of degeneracy in evolution and claimed it led to parasitism and weakness of organ systems or their loss. Jordan used degeneracy theory for both evolutionary studies in animals and his belief in human degeneracy, which led him to become an early founder of the American eugenics movement that Davenport later promoted on a large scale at Cold Spring Harbor in New York [12].

Fig. 1. Carl Eigenmann in a trick mirror photograph about 1914. In the 1915 Indiana University yearbook, *Arbutus*, this photo is accompanied by the legend "Dean Eigenmann holds a committee meeting. The dean concurs in the opinion of the majority of the committee". Eigenmann studied degeneracy in evolution using blind cave fish primarily. EigenmannCarl(IU Archives).tiff Indiana University Archives, Wells Library.

Eigenmann thought cave fauna seemed a good place to study the evolutionary changes of a noxious environment and the hereditary means by which degenerate traits were passed on. In 1886 Eigenmann was handed a specimen of blind fish drawn from a well in the limestone area that surrounds the Indiana University campus. He made several spelunking trips over the next few years and traced the species migrations of cave fauna in the Midwest. This culminated in a 241-page monograph in 1909, published by the Carnegie Institution of Washington [13]. One of Eigenmann's students was William J. Moenkhaus (1871–1947), also a Hoosier, born in Huntingburg, Indiana. He got his Ph.D. at the University of Chicago in 1903. Moenkhaus introduced fruit fly research to Indiana University shortly after that.

4. The spread of fruit fly research shifts from Castle to Lutz, Moenkhaus, and Payne

The work of Castle on fruit flies was getting around. Castle told Frank E. Lutz (1879–1943) at Cold Spring Harbor of its utility for experimental evolution studies that he was launching, and Lutz told Moenkhaus at a meeting there in 1904 of its usefulness. Lutz's experiments using fruit flies were presented in 1907 [14]. He selected wing venation changes, looking for interruptions, forking, or changes in width of the veins. As was characteristic of this Darwinian approach, for each generation all the offspring were